Estimating the Value of Statistical Life in China: A Contingent Valuation Study in Six Representative Cities

Chaoji Cao
Tsinghua University

Xinke Song
Tsinghua University

Wenjia Cai (wcai@tsinghua.edu.cn)
Tsinghua University

Yichao Li
Tsinghua University

Jianhui Cong
Shanxi University

Xueying Yu
Beihang University

Xiaoyue Niu
Pennsylvania State University

Mengzhao Gao
Tsinghua University

Can Wang
Tsinghua University

Research Article

Keywords: health impacts, value of statistical life, contingent valuation method, willingness to pay

Posted Date: February 5th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-199197/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Estimating the Value of Statistical Life in China: A Contingent Valuation Study in Six Representative Cities

Chaoji Cao¹2.3#, Xinke Song⁴#, Wenjia Cai¹2.3*, Yichao Li⁵6, Jianhui Cong⁷, Xueying Yu⁸910, Xiaoyue Niu¹¹, Mengzhao Gao⁵6, Can Wang⁴

¹ Ministry of Education Key Laboratory for Earth System Modeling, Department of Earth System Science, Tsinghua University, Beijing 100084, China

² Center for Healthy Cities, Institute for China Sustainable Urbanization, Tsinghua University, Beijing 100084, China

³ Tsinghua Urban Institute, Tsinghua University, Beijing, 100084, China

⁴ State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China

⁵ Center for Statistical Science, Tsinghua University, Beijing, 100084, China

⁶ Department of Industrial Engineering, Tsinghua University, Beijing, 100084, China

⁷ School of Economics and Management, Shanxi University, Taiyuan, 030000, China

⁸ School of Economics and Management, Beihang University, Beijing, 100191, China

⁹ Beijing Advanced Innovation Center for Big Data-based Precision Medicine, Beihang University, Beijing, 100191, China

¹⁰ Key Laboratory of Big Data-Based Precision Medicine (Beihang University), Ministry of Industry and Information Technology, Beijing, 100191, China

¹¹ Department of Statistics, Pennsylvania State University, PA, 16802, USA

#These authors contributed equally to this work.

*Corresponding author, email address: wcai@tsinghua.edu.cn

Abstract

Incorporating the health impacts into all kinds of policy decisions has become the shared expectations of policymakers and the public, hoping to obtain the most significant health benefits with the least policy costs. The value of statistical life (VSL), which represents the additional cost that individuals are willing to reduce the risk of death, is a core tool for monetizing health impacts. Though VSL has been widely studied internationally, the existing VSL research in China has limitations on regional representativeness, questionnaire design, and discussion of influencing factors. To fill these research gaps, we selected six representative cities in six typical provinces based on cluster analysis and conducted a face-to-face contingent valuation interview (n=3936) from March 7, 2019, to September 30, 2019, using the hypothetical vaccine as the payment tool followed by double-bounded dichotomous choice questions. The respondents' willingness to pay (WTP) to reduce the death risk from air pollution was elicited and used to quantify the VSL of typical urban residents. Also, we discussed the determinants of WTP and VSL in comparison with
previous studies. Results showed that the WTP varied from 455-763 yuan, corresponding to a VSL range of 3.79-6.36 million yuan (price in 2019) in different cities. Therefore, the VSL in China in 2019 was estimated to be 5.10 million yuan, which was 1.2-41 times of the previous studies (in 2019 price). It was also proven that influencing factors such as monthly expenditure levels, environmental concerns, risk attitudes, and assumed market acceptance, which had been seldom discussed in previous studies, had significant impacts on the WTP and the VSL. There were substantial differences in the influencing factors of residents' WTP in different cities, which provided a reasonable explanation for the large gap of the VSL among six representative cities.

**Keywords:** health impacts; value of statistical life; contingent valuation method; willingness to pay
1. Introduction

In June 2013, “Health in all policies” was formally proposed by the World Health Organization in the 8th Global Conference on Health Promotion, calling for the inclusion of the health impact assessment into different sectors policy decisions in all countries, in order to obtain the most significant health benefits with the least policy costs. Therefore, monetizing health impacts becomes a crucial step in carrying out a cost-benefit analysis of all kinds of policies. The value of statistical life (VSL), which represents the additional cost that individuals are willing to reduce the risk of death (Viscusi and Aldy, 2003), is a core tool for monetizing health impacts. As one of the most critical values in the economic assessment of health impact, many countries worldwide are committed to providing authoritative and accurate data used as the basis for policymaking. For example, in the United States, the Environmental Protection Agency regularly updates the VSL to support health impact monetization (EPA, 2015). However, in China, the current researches on the VSL can hardly fulfill the abovementioned policy needs, mainly because of a lack of comprehensive VSL data, which is scientific and can reflect socio-economic and environmental differences in different regions.

There are three main research gaps for previous VSL studies in China. First, most of the existing VSL researches have only been carried out in some first-tier and second-tier cities so far like Beijing, Shanghai, Chongqing, Chengdu etc. (Guo et al., 2006; Hoffmann et al., 2017; Wang and Mullahy, 2006; Zhang, 2002), without a proper statement on how representative this research area was in the background of huge variances in socio-economic and environmental status across different regions in China. Second, existing studies might have limitations in the questionnaire design. In order for the interviewees to understand hypothetical markets and be sensitive to small changes in health risks, the survey needs to have detailed background descriptions, clear and specific payment tools, easy-to-understand probability explanations, and action time definitions, etc. However, existing studies hardly fulfill all of the above-mentioned criteria. Besides, current research in China rarely uses pre-survey to improve the questionnaire, which may also cause defects in questionnaire design (Sun et al., 2016; Wei and Wu, 2017). There are significant differences among different research results; for example, the minimum value of the research results in the existing literature is US$15,000 (price in 1999), and the highest is US$614,805 (price in 2016) (Hammitt and Zhou, 2006; Hoffmann et al., 2017). Third, existing literature has a preliminary discussion of influencing factors. The determinants of the VSL can be categorized as demographic and socio-economic factors, factors identified in the public health literature, and factors identified in the social science literature (Istamto et al., 2014), but most of the existing literatures lack the discussion of the factors related to personal health status and respondents’ perceptions. In summary, existing studies have limitations on regional representativeness, questionnaire design, and discussion of influencing factors. The VSL valuation results in China vary considerably among studies, making it difficult to provide strong support for policymaking.

To fill these research gaps, this research used cluster analysis to select representative cities that can reflect the differences in socio-economic and environmental characteristics among regions. We designed a set of survey questions based on extensive literature research, expert consultation, and pre-survey. We collected data on the influencing factors of statistical life value identified in the existing literature, including demographic and socio-economic factors and the factors related to personal health and subjective perception. The research investigated the respondents' willingness to
pay (WTP) for reducing the death risk from air pollution, thereby quantifying the VSL of typical urban residents and analyzing its influencing factors. Our research established VSL data of Chinese residents considering the differences in socio-economic and environmental characteristics among regions. It could provide data support for the economic evaluation of health impacts for policy decisions in various fields, such as public health, earthquake prevention, disaster reduction, etc. The remainder of this paper is organized as follows. Section 2 introduces the survey design. Section 3 describes the survey data, statistical methods, and estimation results. Section 4 discusses the determinants of WTP and VSL in comparison with previous studies. Section 5 concludes with research implications.

2. Methods

2.1 Questionnaire Design

Contingent valuation method (CVM), a survey-based method, directly examines the amount of money people are willing to pay for a certain risk reduction of death in a hypothetical choice. CVM is good at comprehensively reflecting economic loss and disutility (Oriordan et al., 1987; Venkatachalam, 2004). Based on the NOAA report's guidelines (Arrow et al., 1993), the pretested contingent valuation (CV) questionnaire consists of four parts. The first part is the survey on the willingness to pay. In this part, we provide a detailed background which introduces the cause, harm, and situation of air pollution, and we use a risk-money tradeoff question to elicit the respondents' WTP for reducing the risk of death from air pollution, thereby quantifying the value of statistical life of typical urban residents. In the second part, a survey on the respondent's characteristics is designed, including two types of determinants: 1) factors identified in the public health literature, including outdoor exercise frequency of the respondent and his family, occupational exposure, whether the respondent or the respondent's families being outdoor staff, exercise habits and smoking habits; 2) factors identified in the social science literature, including the level of knowledge of air pollution, self-reported current air pollution, environmental concern, aspect of health status, attitudes to risk, recognition degree of hypothetical market. The third part is designed to collect demographic and socio-economic information of the respondents. The fourth part is interviewer evaluation questions answered by the interviewers after they finish the three parts mentioned above with the respondent.

WTP is elicited by a hypothetical and detailed-described market. In this market, the vaccine is selected as the payment tool for two reasons. First, the public is highly familiar with vaccines, which can reduce the possibility that the public will refuse to answer because they are not familiar with the market. Second, individuals can only use vaccines to exert their own effectiveness, eliminating the potential "free rider" and "warm glow" of other payment tools. For example, pollution control projects as payment tools are likely to cause problems such as "free-riding" and "warm glow." "Free-riding" will make respondents consider the positive effects of other people's payments to themselves and reduce their payments. "Warm glow" will cause respondents to increase their payment for the positive utility brought to others. Both of these situations will eventually cause an inaccurate valuation. Other necessary information such as the vaccine's function, production and safety assurance, the effective time of action, and no side effects are described in detail, ensuring the market is realistic and acceptable for the respondents. The WTP questionnaire is shown in section 7 (S7) of the supplementary information.
This research uses double-bounded dichotomous choice (DBDC) elicitation formats, which can efficiently capture the interviewee's WTP (Hanemann et al., 1991; Kanninen, 1993). Each respondent is asked whether he would purchase the vaccine at a specified price after a card showing the price of eight common vaccines varying from 80-4000 yuan. The specified price, or the initial bid amount, is selected from a set of initial values obtained from the available literature and pretest results, including 200, 400, 600, and 800. The respondent is then asked a follow-up dichotomous-choice question. If he responds "yes" to the initial bid, the follow-up bid will be twice as large as the initial bid; if he responds "no" to the initial bid, the follow-up bid will be half as large as the initial bid. For respondents who said "no" to both initial and follow-up questions, the lower bound is assumed to be zero. For respondents who said "yes" to both initial and follow-up questions, the upper bound is infinity (Hammitt and Zhou, 2006). Thus, the WTP is interval-censored. Using both the first and second responses substantially increases the statistical power of the WTP estimate, i.e., it tends to produce a much tighter confidence interval for the WTP estimate for any fixed sample size (Carson et al., 2003).

The hypothetical market may cause stated preferences to deviate from true preferences, so we use the effect test to consider the impact of changes in a particular element in the hypothetical market design on the WTP to determine the results' reliability. According to existing literature (Guo et al., 2006; Hammitt and Zhou, 2006; Hoffmann et al., 2012), we included the test of the scale effect and the sensitivity of the initial value of risk in this research. Additionally, considering that air pollution may be affected by the seasons, especially in the northern regions where the air pollution changes significantly from non-heating season to heating season. We conducted the test on three hypotheses as follows and collected 200 samples for each test.

- The seasonal effect: The seasonal effect test hypothesizes that the polluting weather during the heating season will not affect the respondents' WTP. Therefore, data are collected during the heating season to test the hypothesis.

- The sensitivity of initial risk of death: The hypothesis of the sensitivity test of the initial value of risk is: the respondents' WTP is not sensitive to the initial value of risk. If the hypothesis is rejected, the WTP amount collected in this part of the questionnaire will be inconsistent with the standard questionnaire, and there will be a big gap. The corresponding questionnaire design is: "according to the national death statistics and experimental data of this vaccine, if a person is vaccinated with this vaccine, the probability that he will die every year due to air pollution will reduce from an initial level of 22 in 100,000 to 10 in 100,000, which means 12 in 100,000 of the death risk reduction."

- The scale effect: The scale effect test hypothesizes that the respondents' WTP is not sensitive to the extent of risk reduction. If the hypothesis is rejected, the amount of WTP collected in this part of the questionnaire will be twice that of the standard questionnaire. The corresponding questionnaire design is: "according to the national death statistics and experimental data of this vaccine, if a person is vaccinated with this vaccine, the probability that he will die every year due to air pollution will reduce from an initial level of 82 in 100,000 to 58 in100,000, which means 24 in 100,000 of the death risk reduction."

2.2 Selection of Research Areas

As stated before, the previous literatures have seldom discussed the representativeness of the research areas. Therefore it is not sure that the different socio-economic and environmental development characteristics in different provinces can be reflected comprehensively. Besides, as
CV study is usually very costly and time-consuming, it's not practical to conduct this survey in too many cities. In this research, based on the selected determinants of WTP in this series of studies, two steps of cluster analysis are used to select typical cities.

14 indicators in 3 categories are selected as clustering indicators based on previous studies (Akhtar et al., 2017; Alberini et al., 1997; Istamto et al., 2014; Sun et al., 2016; Wang and Mullahy, 2006; Wang et al., 2015; Wang and Zhang, 2009; Wei and Wu, 2017; Yang and Xu, 2004; Yin et al., 2018), including: 1) social characteristics, i.e. the proportion of the population with a high school education over the age of 6, the proportion of persons covered of basic medical care insurance, household size, sex ratio, dependency ratio, all-cause mortality of PM$_{2.5}$, which are used to reflect the level of social development, population characteristics, medical development situation and health status; 2) economic characteristics, i.e. per capita disposable income, per capita consumption expenditure, urban/ rural consumption ratio, which are used to reflect the level of economic development, consumption level and rural-urban difference of economics; 3) environmental characteristics, i.e. average good air quality days, the annual mean concentration of PM$_{2.5}$, the annual mean concentration of PM$_{10}$, the annual mean concentration of SO$_2$, the annual mean concentration of NO$_2$, which are used to reflect regional pollution.

The cluster analysis was conducted to divided 30 provinces (except Hong Kong, Macau, Taiwan, and Tibet) into N categories. Combined principal component analysis (PCA) and K-means cluster analysis methods, 30 provinces were grouped into 6 categories. Then, the distance differences between all prefecture-level cities and each index's average level in a certain province were calculated. Considering both operability and representativeness, we identified six representative cities, i.e., Beijing (BJ), Jinzhong in Shanxi (JZ), Yangzhou in Jiangsu (YZ), Ganzhou in Jiangxi (GZ), Shantou in Guangdong (ST), Siping in Jilin (SP). The results of the cluster analysis were shown in Table 1.

| Provinces in each category | Typical province | Representative city |
|----------------------------|------------------|---------------------|
| Beijing, Shanghai          | Beijing          | Beijing             |
| Shanxi, Shaanxi, Xinjiang, Anhui | Shanxi     | Jinzhong            |
| Ningxia, Hebei, Hubei, Henan | Jiangsu       | Yangzhou            |
| Jiangsu, Tianjin           | Jiangxi          | Ganzhou             |
| Jiangxi, Guangxi, Qinghai, Yunnan | Guangdong | Shantou             |
| Gansu, Hunan, Guizhou, Hainan | Jilin         | Siping              |
| Guangdong, Fujian, Zhejiang |                 |                     |
| Jilin, Inner Mongolia, Chongqing, |                 |                     |
| Liaoning, Sichuan, Shandong, Heilongjiang | Jilin       |                     |

2.3 Data Collection

A sample of 4254 respondents was interviewed from March to September 2019. The seasonal effect test samples are collected from March 7, 2019 to March 15, 2019 (in the heating season), and the remaining samples were collected from May 1, 2019 to September 30, 2019. Interviewers were recruited from undergraduate students in local universities and a research company with
professional qualifications. Then we trained these interviewers on detailed knowledge of CV, the questionnaire's design information, and how to introduce this questionnaire survey. We also offered a list of references for the questions that might be asked. These interviewers were followed in some interviews to ensure validity.

Respondents were selected by stratified sampling methods. The sample size was 600 in each research city, and the sample size in each district was determined by the population proportion of one district in one research city. The survey sites were then selected by parks, commercial districts, schools, and recreational places with a large flow of people from different districts. We required that the sample size be less than 10 at the same location. 10 districts in Beijing were visited, i.e., Dongcheng, Xicheng, Haidian, Chaoyang, Fengtai, Shijingshan, Tongzhou, Daxing, Changping, and Mentougou. The sampleS of effect tests were collected in Haidian, Chaoyang, Fengtai, and Shijingshan district. Besides, due to lack of population data in some districts, we adopted an even distributed sampling in Jinzhong.

A face-to-face random central intercept interview was conducted in this survey. Then, pretreatment was used to filter valid questionnaires. Respondents with age under 18 or satisfied any one of these four conditions in the interviewer evaluation questions were excluded: 1) the interviewer judged that the respondents did not understand the air pollution information provided by the questionnaire; 2) the respondents failed to cooperate from the beginning to the end of the interview; 3) the respondents were greatly influenced by others during the interview; 4) the response to the willingness to pay was not prudent. Finally, 3936 valid samples were screened out (Table 2).

| Area/module         | Collected | Identified as invalid by the interviewers | With respondents under 18 | Valid |
|---------------------|-----------|------------------------------------------|---------------------------|-------|
| Beijing             | 703       | 64                                       | 12                        | 627   |
| Jinzhong            | 599       | 23                                       | 7                         | 569   |
| Yangzhou            | 603       | 49                                       | 1                         | 553   |
| Ganzhou             | 610       | 67                                       | 3                         | 540   |
| Shantou             | 571       | 9                                        | 3                         | 559   |
| Siping              | 568       | 15                                       | 0                         | 553   |
| Seasonal effect     | 190       | 19                                       | 6                         | 168   |
| Sensitivity of initial risk of death | 209       | 21                                       | 1                         | 187   |
| Scale effect        | 201       | 21                                       | 0                         | 180   |
| **Total**           | **4254**  | **288**                                  | **33**                    | **3936** |

2.4 Regression Model for WTP and VSL

Four types of response to four initial bids resulted in 16 WTP intervals. Taking 200 as an example.: the respondent was asked whether he would like to pay 200 yuan for the vaccine, if he
responded "yes" to the initial bid, the follow-up bid would be 400 yuan, and the WTP interval would be \([400, +\infty]\) if he voted for again, or the WTP interval would be \([200, 400]\); if he responded "no" to the initial bid, the follow-up bid would be 100 yuan, and the WTP interval would be \([100, 200]\) if he said "yes" or the WTP interval would be \([0, 100]\). All intervals were shown in Table 3.

| The initial bid | Yes-Yes       | Yes-No       | No-Yes       | No-No       |
|-----------------|---------------|--------------|--------------|--------------|
| 200             | \([400, +\infty]\) | \([200, 400]\) | \([100, 200]\) | \([0, 100]\) |
| 400             | \([800, +\infty]\) | \([400, 800]\) | \([200, 400]\) | \([0, 200]\) |
| 600             | \([1200, +\infty]\) | \([600, 1200]\) | \([300, 600]\) | \([0, 300]\) |
| 800             | \([1600, +\infty]\) | \([800, 1600]\) | \([400, 800]\) | \([0, 400]\) |

Considering interval-censored data, we applied interval regression in this analysis (Carson et al., 2003). We obtained a sample containing \(i=1, 2, \ldots, n\) agents with statistically independent \(Y_i\), \(Y_i\) was defined as \((Y_{il}; Y_{ir})\), \(Y_{il}\) and \(Y_{ir}\) respectively represent the left endpoint and the right endpoint of willingness to pay. The range of \(Y_{il}\) is \([0, 1600]\), and the range of \(Y_{ir}\) is \([0, +\infty]\). If \(Y_{il}\) was independent of \(Y_{ir}\), \(X_{ij}\) represented the \(j_{th}\) variable of the \(i_{th}\) sample, then the likelihood function can be written as follows:

\[
\log L = \sum_{i=1}^{n} \log \left[ \theta \left( \frac{Y_{il} - \mu_i}{\sigma} \right) \right] - \theta \left( \frac{Y_{ir} - \mu_i}{\sigma} \right) \]

(1)

\[
\mu_i = \sum_{j=1}^{p} \beta_{ij} X_{ij} \]

(2)

Where \(\beta_j\) and \(\sigma\) are unknown parameters to be estimated. Assuming that \(\theta\) conforms to the normal distribution, the above likelihood function can be optimized to obtain the maximum likelihood estimation of parameters as \(\hat{\beta}_1\), \(\ldots\), \(\hat{\beta}_p\), \(\hat{\sigma}^2\). Then the numerical method was used to calculate the mean WTP for each research city.

Turning to the estimation of VSL, the life-cycle model was used to deduce (Alberini et al., 2004; He and Wang, 2010). Assume that a person expected utility of \(V_j\) of his remaining years at the age \(j\), thus

\[
V_j = \sum_{t=j}^{T} q_{j,t} (1 + \rho)^{t-j} u_t (C_t) \]

(3)

Where \(u_t (C_t)\) is the utility of consumption in the period \(t\) of this person. Multiplying it with the probability that the person survives to that period \(q_{j,t}\) and discounting it with the subjective rate of time preference \(\rho\), the present value of \(u_t (C_t)\) can be computed.

\[
q_{j,t} = (1 - D_j) (1 - D_{j+1}) \ldots (1 - D_{t-1}) \]

(4)

Thus, if \(D_j\) decreases, the probability that a person survives in the future will increase. And we can obtain how much initial wealth \(W_j\) this person would like to give up to reduce \(D_j\), and \(D_j\) represents the probability that he dies during the \(j\) period. Besides, the maximization of \(V_j\) depends on the initial wealth \(W_j\) and budget constraints that reflect borrowing and lending opportunities, and a person will never be a net borrower though he can borrow at a riskless rate \(r\).
\[ W_t = W_j + \sum_{k=j}^{t} \frac{y_k - C_k}{(1+r)^{k-j}} \geq 0 \]  

(5)

Where \( y \) is income and \( C \) is consumption.

The substitution rate between \( W_j \) and \( D_j \) keeps the expected utility \( V_j \) to be constant. \( V_j \) reflects the VSL of this person in age \( j \). Thus we can define VSL as

\[ VSL_j = \frac{\partial V_j / \partial D_j}{\partial W_j / \partial D_j} \]  

(6)

Where \( dW_j \) is the price a person would like to pay for the reduction of \( D_j \), VSL is the marginal value of risk change. As for CVM, though the risk reduction of death for a person is usually small, WTP effectively records the amount that the respondents will pay for the slight risk reduction. Therefore, the VSL can be roughly equal to the average WTP of the risk reduction, shown as

\[ VSL_j = \frac{WTP_j}{\partial D_j} \]  

(7)

To explore the determinants of WTP, we used the likelihood ratio test to examine the significance of each factor discussed in this survey.

\[ 2 \times \left[ \log \left( L(\beta_1, ..., \beta_p, \sigma^2|Y) \right) - \log L(\beta_1, ..., \beta_{l-1}, \beta_{l+1}, \sigma^2|Y) \right] \sim_{approx} \chi^2_{df} \]  

(8)

Where \( df \) is the degree of freedom. If the variable is continuous, \( df \) equals 1. If it is a discrete variable, \( df \) equals the number of discrete values of the variable minus 1.

3. Results

3.1 Data Description

As mentioned in Chapter 2.3, 3,936 valid questionnaires remained after screening. Due to the abovementioned double-bounded dichotomous-choice elicitation framework, four types of the WTP response differed for each initial bid: the yes-yes response, the yes-no response, the no-yes response, and the no-no response (the "not sure" responses were regarded as "no" responses in this count). Table S1 showed the frequencies of each response type for each initial price in the WTP question.

3.2 Descriptive Statistics

3.2.1 Negative WTP Response Samples Analysis

Under the double-bounded dichotomous-choice elicitation framework, 791 "no-no" responses are collected. The reasons for the negative responses and the corresponding proportion in each city were shown in Table S2. Except for the option of "other reasons", "I do not believe there is such a
vaccine” accounted for the highest proportion, all exceeding 20%, indicating that the hypothetical market design in this survey might have some defects. If a respondent did not accept the hypothetical market, his WTP was likely to be invalid. To solve the problem of hypothetical market recognition, we used the sub-sample that excluded the sample that chose "not approved or not approved at all of the hypothetical market” in the statistical analysis to avoid the interference of the hypothetical market design on the calculation results.

Although the statement of “the vaccine has certificated by the World Health Organization” and "the production and transportation of this vaccine is now strictly controlled by the country” were repeatedly stressed to ensure the effectiveness and safety of the vaccine in the hypothetical market, a considerable number of respondents chose "the vaccine quality is poor" as the reason for refusing to pay (12%-32%), which implied that the Changchun Changsheng Biotechnology vaccine scandal in China in 2018 might decrease the vaccine acceptance (Hu et al., 2020; Lancet, 2018), and it reflected that the authority and credibility of the healthcare sector in China still need to be improved. Besides, respondents in six cities chose "the vaccine is not worth that much" and "I am healthy enough" as the reasons for rejection, accounting for about 9%-17%. The former reflected the limited trust of respondents in the efficacy of vaccine treatment. In contrast, the latter reflected the confidence of respondents in their own resistance, and both were related to personal characteristics that would be further studied in the later analysis. Only a small part of the respondents in each city chose "I do not believe the harm of air pollution" as the rejection reason, indicating that the survey has a social consensus background. For the "I cannot afford" option, Siping was the city with the highest proportion of this option, corresponding to its relatively low-income characteristics. Beijing was the city with the second-highest proportion of this option, which might be related to the tight budget constraints because of the high living cost.

3.2.2 Descriptive summary for all variables

We have described three categories of variables introduced in this survey, including 26 variables in total. These 26 variables comprise 13 factors collecting demographic and socio-economic information, 6 factors identified in the public health literature, and 7 factors identified in the social science literature. Table 4 showed the definitions for these 26 variables.

Table 4. Definition of variables

| Parameters                      | Variables  | Variable definition                                      |
|--------------------------------|------------|----------------------------------------------------------|
| Factors of demographic and socio-economic characteristics |            |                                                          |
| Ge    | Sex        | 1 if male, 2 if female                                    |
| Age   | age        | Age in years                                             |
| Edu   | education  | Categorical variable from 1 (illiterate) to 7 (Ph.D.)     |
| Inc   | Annual income | Categorical variable from 1 (≤30,000 yuan) to 8 (≥800,001 yuan) |
| Exp   | Monthly expenditure | Categorical variable from 1(≤500 yuan) to 7(≥12,001 yuan) |
| Hs    | Household size | Number of people living in the household                 |
| Mg    | Marriage   | Categorical variable, 1 if unmarried, 2 if married, 3 if divorced, 4 if widowed |
| Code | Description                                                                 | Details                                                                 |
|------|------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Fc   | Fertility condition                                                          | 1 if have children, 2 if have no children                              |
| Nc   | Number of children                                                            | 4 if 4 or more children                                                |
| Agy  | Age of the youngest child                                                    | Categorical variable, 1 if 0-3 years old, 2 if 4-6 years old, 3 if 7-12 years old, 4 if 13-18 years old, 5 if 19-30 years old, 6 if 30 and over |
| Nop  | Number of older people                                                        | Number of people over 60 years old in the household (from 0 to 7, 7 if 7 or more older people) |
| Lclc | Whether the children live locally                                            | Categorical variable, 1 if live locally, 2 if not, 3 if some of the children/elderly live locally |
| Lclo | Whether the old people live locally                                          |                                                                                        |

**Factors identified in the public health literature**

| Code | Description                                                                 | Details                                                                 |
|------|------------------------------------------------------------------------------|------------------------------------------------------------------------|
| IoeF | Individual outdoor exercise frequency                                        | Categorical variable, 1 if three or more times a week, 2 if one or two times a week, 3 if once every half a month, 4 if more than half a month |
| Foef | Family outdoor exercise frequency                                             |                                                                                        |
| Oc   | Occupational classification                                                  | Categorical variable, 1 if indoor staff, 2 if field staff, 3 if unemployed/retired, 4 if students |
| Wot  | Whether the respondent or his families work outdoor                         | Categorical variable, 1 if only the respondent, 2 if only his family, 3 if all, 4 if none. |
| Eh   | Exercise habits                                                              | 1 if yes, 2 if no exercise                                               |
| Sh   | Smoking habits                                                               | 1 if yes, 2 if no smoking                                                |

**Factors identified in the social science literature**

| Code | Description                                                                 | Details                                                                 |
|------|------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Kap  | Level of knowledge of air pollution                                          | Categorical variable, 1 if all, 2 if part, 3 if not at all, 4 if not sure |
| Rap  | Self-reported current air pollution                                          | The severity of air pollution, categorical variable, 1 if not at all, 2 if slightly, 3 if moderately, 4 if very, 5 if extremely |
| Ec   | Environmental concern                                                        | Self-reported whether environmentalist, 1 if strongly agree, 2 if agree, 3 if not sure, 4 if disagree, 5 if strongly disagree |
| Shs  | Self-reported health status                                                   | Categorical variable, 1 if very good, 2 if good, 3 if fair, 4 if poor, 5 if very poor |
| Prp  | Perception of change in health status compared to last year                  | Categorical variable, 1 if better, 2 if no change, 3 if worse           |
| Atd  | Attitudes toward risk                                                        | Categorical variable, 1-4 if risk aversion, the degree of risk aversion is weakened, 5-6 if risk preference, the degree of risk preference is increased. |
| Rec  | Recognition degree of hypothetical market                                    | Categorical variable, 1 if strongly agree, 2 if agree, 3 if undecided, 4 if disagree, 5 if strongly disagree |
Detailed descriptive values were shown in Table 5. There are significant regional differences for some factors.

| Variable | BJ    | JZ    | YZ    | GZ    | ST    | SP    | TOTAL |
|----------|-------|-------|-------|-------|-------|-------|-------|
| Edu      | 4.47  | 4.36  | 4.2   | 4.62  | 4.07  | 4.32  | 4.34  |
|          | (1.35)| (1.32)| (1.31)| (1.46)| (1.32)| (1.3) | (1.35)|
| In       | 2.05  | 1.97  | 2.43  | 2.29  | 2.34  | 1.64  |       |
|          | (0.99)| (1.17)| (1.49)| (1.44)| (1.49)| (1.07)| -     |
| Exp      | 3.77  | 3.52  | 3.9   | 3.8   | 3.86  | 3.2   | 3.68  |
|          | (1.26)| (1.24)| (1.33)| (1.24)| (1.4) | (1.39)| (1.33)|
| HS       | 2.62  | 3.4   | 3.75  | 3.76  | 4.71  | 3.2   | 3.55  |
|          | (1.56)| (1.58)| (1.61)| (1.74)| (1.71)| (1.36)| (1.72)|
| Mg       | 1.54  | 1.72  | 1.8   | 1.64  | 1.59  | 1.53  | 1.63  |
|          | (0.52)| (0.5) | (0.44)| (0.5) | (0.5) | (0.53)| (0.51)|
| Fc       | 1.52  | 1.33  | 1.24  | 1.43  | 1.46  | 1.52  | 1.42  |
|          | (0.5) | (0.47)| (0.43)| (0.5) | (0.5) | (0.5) | (0.49)|
| Nc       | 1.39  | 1.45  | 1.27  | 1.8   | 2.12  | 1.25  | 1.53  |
|          | (0.59)| (0.62)| (0.53)| (0.76)| (0.87)| (0.47)| (0.72)|
| Agy      | 3.41  | 3.66  | 3.81  | 3.31  | 3.1   | 3.95  | 3.55  |
|          | (1.76)| (1.78)| (1.64)| (1.8) | (1.57)| (1.6) | (1.72)|
| Nop      | 2.3   | 2.69  | 3.09  | 2.85  | 2.52  | 2.67  | 2.69  |
|          | (1.28)| (1.32)| (1.49)| (1.46)| (1.35)| (1.55)| (1.43)|
| Lelc     | 1.52  | 1.32  | 1.23  | 1.36  | 1.28  | 1.28  | 1.33  |
|          | (0.55)| (0.6) | (0.49)| (0.64)| (0.57)| (0.51)| (0.57)|
| Lclo     | 1.76  | 1.58  | 1.54  | 1.58  | 1.3   | 1.4   | 1.53  |
|          | (0.51)| (0.65)| (0.73)| (0.68)| (0.58)| (0.59)| (0.64)|
| Factors identified in the public health literature |
| Ioeff    | 1.71  | 1.53  | 1.62  | 1.76  | 1.96  | 1.71  | 1.71  |
|          | (1.01)| (0.84)| (0.95)| (0.97)| (1.07)| (0.99)| (0.98)|
| Foef     | 1.76  | 1.53  | 1.56  | 1.61  | 1.81  | 1.81  | 1.68  |
|          | (1.01)| (0.86)| (0.88)| (0.95)| (1.04)| (1.04)| (0.97)|
| Oc       | 1.88  | 1.9   | 1.53  | 1.84  | 1.63  | 2.2   | 1.83  |
|          | (1.06)| (1.13)| (0.97)| (1.13)| (1.08)| (1.25)| (1.12)|
| Wot      | 3.22  | 3.27  | 3.28  | 3.23  | 3.42  | 3.32  | 3.29  |
|          | (1.05)| (1.02)| (1.03)| (1.03)| (0.96)| (0.98)| (1.01)|
| Eh       | 1.24  | 1.25  | 1.28  | 1.29  | 1.3   | 1.25  | 1.27  |
|          | (0.43)| (0.44)| (0.45)| (0.45)| (0.46)| (0.43)| (0.44)|
| Sh       | 1.62  | 1.74  | 1.78  | 1.83  | 1.78  | 1.7   | 1.74  |
|          | (0.49)| (0.44)| (0.41)| (0.37)| (0.41)| (0.46)| (0.44)|
Factors identified in the public health literature

|   | Kap    | Rap   | Ec     | Shs    | Prp    | Atd    | Rec    |
|---|--------|-------|--------|--------|--------|--------|--------|
|   | 1.92   | 3.65  | 2.25   | 2.21   | 1.94   | 2.97   | 2.77   |
|   | (0.76) | (0.81)| (0.72) | (0.75) | (0.58) | (1.92) | (0.89) |
|   | 1.81   | 3.39  | 2.06   | 2.18   | 1.94   | 3.01   | 2.5    |
|   | (0.7)  | (0.73)| (0.87) | (0.84) | (0.63) | (1.73) | (0.89) |
|   | 1.9    | 3.18  | 2.17   | 2.2    | 1.87   | 2.92   | 2.6    |
|   | (0.75) | (0.71)| (0.81) | (0.81) | (0.62) | (1.9)  | (0.86) |
|   | 1.87   | 2.81  | 2.3    | 2.41   | 1.84   | 3.08   | 2.57   |
|   | (0.74) | (0.72)| (0.82) | (0.82) | (0.66) | (1.69) | (0.77) |
|   | 2.07   | 3.03  | 2.4    | 2.21   | 1.93   | 2.79   | 2.48   |
|   | (0.81) | (0.81)| (0.88) | (0.81) | (0.67) | (1.68) | (0.78) |
|   | 2.12   | 3.21  | 2.34   | 2.34   | 1.98   | 2.66   | 2.6    |
|   | (0.87) | (0.82)| (0.88) | (0.81) | (0.58) | (1.82) | (0.84) |
|   | 1.95   | 2.07  | 2.23   | 2.26   | 1.92   | 2.91   | 2.59   |
|   | (0.78) | (0.81)| (0.68) | (0.81) | (0.62) | (1.8)  | (0.85) |

(Notes: The mean value and standard deviation in parenthesis for each variable were displayed. The mean annual income of the total sample was not calculated in the table due to the different income categories set between Beijing and other cities.)

3.3 Estimation Results of WTP and VSL

Given that the reduction of death risk was 12/100,000, respondents could show their own WTP for this risk reduction. To estimate the mean WTP based on individual WTP in six research cities, we conducted maximum likelihood estimations with normal distribution function for each research city, as shown in equation (1).

Results show that the mean WTP of a 12/100,000 risk reduction of death was 458 yuan in Beijing, 763 yuan in Jinzhong, 590 yuan in Yangzhou, 761 yuan in Ganzhou, 645 yuan in Shantou, 455 yuan in Siping. The distribution curves of WTP for each city were shown in Figure 1.
Based on the above mean WTP, we calculated the VSL for each research city by equation (7). The mean WTP and the VSL in each city were shown in Table 6.

Table 6. The Values of WTP and VSL in Each City

| City | The value of WTP (yuan) | The value of VSL (million yuan) |
|------|------------------------|-------------------------------|
| BJ   | 458                    | 3.81                          |
| JZ   | 763                    | 6.36                          |
| YZ   | 590                    | 4.92                          |
| GZ   | 761                    | 6.35                          |
| ST   | 645                    | 5.37                          |
| SP   | 455                    | 3.79                          |

According to the values of VSL in six research cities, we could further calculate the mean value of VSL and obtain that the arithmetic average VSL of Chinese residents was 1.5 million, which was 1.2-41 times (in 2019 price) as much as the estimations in previous studies. The average VSL, which was the mean value of six representative cities in six typical provinces, can be more comprehensive to reflect the VSL of Chinese residents than the simple use of a certain city's VSL estimation on behalf of the national level.

4. Discussion

For further discussion, we compare the influencing factors included in this research with some typical previous studies. Considering the impact of heterogeneity of socio-economic conditions on the results, the references used for comparison are mainly focusing on China, including VSL estimation in Chengdu (Guo et al., 2006) and another VSL estimation in Chongqing (Wang and Mullahy, 2006). These two studies covered most of the factors in the three categories mentioned above, offering a useful reference. A reference that uses the same questionnaire to estimate the VSL in eight countries (Hoffmann et al., 2012) is also selected for comparison.

4.1 Determinants of socio-economic characteristics

The effect analysis of socio-economic determinants is shown in Table S3. The research results of Beijing and Ganzhou show that the annual disposable income has a significant impact on WTP and VSL. The higher the annual disposable income is, the higher the WTP and VSL are, which is consistent with the conclusions of Chongqing and Mongolia. This influence direction is still applicable to areas with insignificant impact in this research, i.e., Jinzhong, Yangzhou, Shantou, and Siping. The monthly expenditure is a newly introduced variable in this study. The logic of its introduction is that the willingness to pay evaluated by the research may be not only affected by income level but also related to the individual’s ability to pay and payment habits. Results show that the WTP and VSL in Beijing, Jinzhong, and Shantou are affected by monthly expenditure, and the
higher the monthly expenditure is, the higher the estimation is. In the other three cities, the monthly expenditure has no significant impact on WTP and VSL. It is worth noting that the annual disposable income in Shantou has no significant impact, while the monthly expenditure has a significant impact, indicating that the monthly expenditure may be the key determinants of WTP and VSL. The possible explanation is that disposable income does not represent the individual's expenditure habits and ability. For example, a resident may have high disposable income but prefer saving or need to pay loans. Therefore, the introduction of monthly expenditure in this research is necessary to better reveal the individual's expenditure habits and ability.

As far as education is concerned, only Shantou has a significant impact, which is consistent with the conclusion of two studies in Chongqing and Mongolia; that is, the higher the education level is, the higher WTP for reducing the risk of death is. The possible explanation is that the higher the education, the stronger the ability to understand the small probability of death risk, and the more able to receive the information represented by the change of death risk.

For the family social characteristics, these eight variables have seldom been discussed in the existing studies, and the discussion is also limited in the selected references. As shown in Table S4, the variable of marriage only shows a significant impact on WTP and VSL in Yangzhou, and married respondents give higher WTP and VSL. The effect direction is consistent with the reference literature (Wang and Mullahy, 2006). Fertility, the number of children, and the youngest child's age in the six cities have no significant impact. In Beijing, whether the older people and the children live locally or not has a significant impact. The respondents who need to take care of the older people and children have lower WTP. Additionally, the variable "number of older people" in Beijing and Shantou has a significant impact on WTP and VSL. Still, the coefficient is not consistent, which indicates that the effect of the variable on the WTP and VSL estimation may be affected by other factors, such as the differences in maintenance costs or family values. The impact of household size on WTP and VSL is not significant, which is consistent with the significance of the study in Chengdu.

4.2 Determinants identified in the public health literature

Similar to the socio-economic characteristics, there are few studies on the ten variables identified in the public health literature, and the discussion is also limited in the selected references (Guo et al., 2006; Hoffmann et al., 2012; Wang and Mullahy, 2006). The discussion results of this study are shown in Table S5. The frequency of outdoor exercise and outdoor work of the respondents and their families have no significant impact. Ganzhou's exercise habit has a significant negative impact on WTP and VSL, which is consistent with the direction of the reference study. The possible explanation is that the respondents who are used to exercise tend to think that exercise can strengthen their health and reduce the risk of death. Smoking habits in Beijing and Shantou have a significant negative impact on WTP and VSL. The effect direction is opposite to the reference study. A possible explanation is that respondents with smoking habits are more concerned about eliminating the health effects of smoking by other means.

In Beijing and Ganzhou, the respondent's cardiovascular and cerebrovascular diseases have a significant negative impact on WTP and VSL, which indicates that the treatment costs may tighten the respondents' budget constraints, resulting in a lower WTP. The cardiovascular and cerebrovascular diseases of the respondent's family members in Shantou have a significant positive impact on WTP and VSL. There are two possible explanations: one is that in addition to the family members' cardiovascular and cerebrovascular diseases, there are other factors that jointly affect the WTP estimation; the other is that air pollution is one of the causes of cardiovascular and
cerebrovascular diseases, so respondents may have higher WTP to reduce the risk of death from air pollution. Besides, the respondent's respiratory diseases in Beijing and Jinzhong have a significant positive impact. Based on the regional characteristics of poor air quality in the two cities mentioned in Chapter 3.2, it is suggested that the respondents in the two cities may attribute the respiratory diseases to the severe air pollution and are willing to pay more for reducing the risk of death related to air pollution.

In Ganzhou, the occupational classification has a significant impact. Still, the direction is uncertain for each discrete value, and the coefficient of the field staff is negative, which reflects that the WTP of field staff is lower. The possible explanations are: 1) they prefer to adopt other forms of risk avoidance; 2) they are less sensitive to air pollution risks because they are more accustomed to air pollution exposure.

4.3 Determinants identified in the social science literature

Factors identified in the social sciences literature have seldom been discussed in previous studies. Eight factors are discussed in this research, and the results are shown in Table S6. It indicates that although factors including the level of knowledge of air pollution and self-reported current air pollution show regional differences, the two variables have no significant impact on estimating the WTP and VSL, consistent with the significance discussions of the reference study. From the positive and negative coefficients of the impact, in terms of the level of knowledge of air pollution, the impact direction of the six cities is consistent. It is pointed out that the more the respondents know about the air pollution information, the higher their WTP is. For most of the cities included in this research, the more serious the air pollution is, the higher their WTP is, which is consistent with the logic that the higher risk of death from air pollution leads to the higher WTP.

The impact of environmental concern on WTP and VSL is significantly negative in Yangzhou, which is consistent with the higher proportion of respondents who think they are environmentalists. This result indicates that when people are more likely to know about the information and risk of air pollution, they will be more willing to pay for the reduction of the risk of death from air pollution. As for attitudes toward risk, the variable is only realized as having a significant positive impact on WTP and VSL in Jinzhong. However, the effect direction is opposite to the reference literature. A possible explanation is that the risk preference scale given in the questionnaire is related to money. The higher the risk preference degree is, the more relaxed the budget constraint is. Therefore, the respondents with higher risk preference have higher WTP and higher VSL. As for health status, the self-reported health status in Beijing has a significant impact on WTP and VSL. The respondents who think their health status is poor have higher WTP and VSL, which applies to cities except Yangzhou and Siping. The perception of health status change compared to last year has no significant impact in the six cities. The recognition degree of the hypothetical market has a significant positive impact in six research cities; that is, the higher the recognition degree is, the higher the WTP and VSL are. In Chapter 3.2, there are noticeable regional differences in vaccine recognition. The average vaccine approval degree in Beijing, Yangzhou, and Siping is relatively low, and the WTP and VSL in these three cities are the last three among the six cities accordingly. The evaluation is consistent with the character analysis of recognition degree, which shows that the hypothetical market design is the key in CVM research.

4.4 Difference comparison of impact among six research cities

From the above analysis of influencing factors, it is shown that the impact of different
The socio-economic and environmental conditions of different cities differ significantly in China. These differences may lead to variances in the influence of the three types of influencing factors on WTP, making the inconsistent evaluation of WTP. For example, Beijing residents are faced with a higher fixed cost of living (such as rent, food, etc.), so the monthly expenditure is an essential factor to affect their WTP. However, residents in Ganzhou have a lower living cost, and the monthly expenditure does not affect the residents' payment habits and ability to pay. Besides, since WTP is a subjective evaluation of the value of one's own life, residents with different socio-economic and environmental attributes are likely to be different, and the proportion of different types of residents in different cities differs greatly.

Based on the difference in the WTP value and the impact of influencing factors among cities in this research, we suggested that when designing questionnaires for similar WTP studies in the future, it is necessary to consider the different socio-economic backgrounds among cities, and broadly discuss the socio-economic development characteristics.

### 4.5 Results of the sensitivity of initial risk of death, scale effect, and seasonal effect

As described in Chapter 2.1, the effect test in this study includes three parts: the sensitivity of initial risk of death, the scale effect, and the seasonal effect. The effect test samples were collected in Haidian, Chaoyang, Fengtai, and Shijingshan district in Beijing. The two-sample t-test is conducted between the test samples and the Beijing sample in the interval regression model. The results of these three effect tests are shown in Table 8. Only the sensitivity of initial risk of death has a significant impact on the WTP. The lower the initial risk of death is, the higher WTP is, which indicates that people with a lower risk tend to value the reduction of death risk; in other words, people in low-risk environments are more likely to cherish their lives. However, this is contrary to the conclusion that respondents with a higher initial risk maybe pay more than those with a lower initial risk of death (Guo et al., 2006). The scale effect and the seasonal effect do not have a significant impact on the WTP. As for the scale effect, it is found that the WTP is not exactly proportionate to the scale change of death risk. There are two possible explanations for this: one is that the death risk in the questionnaire is too small for respondents to understand and to make
payment choices based on small changes in death risk; the other is that the key factor influencing respondents' choice is the subjective probability other than the risk reduction offered in the questionnaire (Mitchell et al., 1989). For seasonal effect, although the WTP influenced by people's subjective judgment on air pollution is not affected by the season change, the evaluation in heating season is higher than that of reference samples, which implies that respondents may have a greater probability to believe the existence of air pollution, and thus give a higher WTP.

Table 8. Summary of Influencing Factors in Six Research Cities

| Sample category                        | WTP (yuan) | P-value |
|----------------------------------------|------------|---------|
| Beijing                                | 458        | -       |
| The sensitivity of initial risk of death| 618        | 0.0009  |
| Scale effect                           | 606        | 0.11    |
| Seasonal effect                        | 635        | 0.18    |

5. Conclusion and suggestion

In the context of the severe air pollution control challenge in China and the research gap that existing researches in China have limitations on regional representativeness, questionnaire design, and discussion of influencing factors, we conducted a face-to-face random central intercept interview in six representative cities with a pretested contingent valuation questionnaire. It quantified the Chinese VSL by eliciting the respondents' WTP for reducing the death risk from air pollution. The main conclusions are as follows:

First, based on the cluster analysis of inter-provincial and intra-provincial variable data affecting VSL in previous studies, six representative cities in the typical provinces were selected for this research. 77% of the respondents were willing to pay to reduce their risk of death from air pollution. The WTP varied from 455-763 yuan, and the WTP in Jinzhong was the highest while the WTP in Siping was the lowest.

Second, the VSL in six representative cities varied from 3.79-6.36 million yuan, i.e., 3.81 million yuan in Beijing, 6.36 million yuan in Jinzhong, 4.92 million yuan in Yangzhou, 6.35 million yuan in Ganzhou, 5.37 million yuan in Shantou, and 3.79 million yuan in Siping. According to the average VSL of the six representative cities, the VSL of Chinese citizens was 5.10 million yuan, which was 1.2-41 times the previous studies (in 2019 price). There are significant differences among VSL in different cities, implying that it is necessary to select typical cities in various regions with different socio-economic and environmental development characteristics to conduct VSL studies.

Third, it was found that influencing factors such as monthly expenditure levels, environmental concerns, risk attitudes, and assumed market acceptance, which have been seldom discussed in previous studies, have significant impacts on WTP and VSL. Besides, the significance level and the impact direction of these six cities' influencing factors varied, which might be due to different cities' socio-economic and environmental conditions.

Fourth, in the effect test, the sensitivity of initial risk of death has a significant impact on the WTP, and people with a lower risk tend to value the reduction of death risk. However, the scale effect and the seasonal effect do not have a significant impact on the WTP. The WTP is not strictly proportionate to the scale change of death risk, and the WTP influenced by people's subjective judgment on air pollution is not affected by the season change.
Based on the abovementioned conclusions, there are three suggestions for future research:

First, the questionnaire design in the future can appropriately include health or perception factors with individual characteristics such as drinking habits, hospital treatment frequency, life expectancy, and people's expectation of future air quality improvement, which may also have an impact on the value of WTP and VSL. Besides, due to time constraints, this research does not explore how the factors affect urban residents' WTP and why some factors have significant impacts while others are not. They can be topics for future research.

Second, considering the significant influence of the initial risk of death, two or more levels of the initial value can be set to conduct group comparison in future questionnaire design. The scale effect is not significant, indicating that respondents are not sensitive to risk reduction. A possible explanation is that respondents cannot understand the low probability of death risk or make payment judgment based on subjective probability. Future questionnaire design could continue to explore innovative interpretation methods that can better help respondents understand the small likelihood of death risk. Additionally, though the seasonal effect was not significant, people showed a higher WTP during the heating season, so the results could be averaged after conducting surveys in different seasons.

Third, considering that the WTP and the VSL show apparent differences in different cities due to the different socio-economic and environmental development in different regions. Therefore, WTP research in a specific city cannot derive the average VSL in China. Since there is a significant regional and population heterogeneity in China, it is essential to conduct studies either through typical cities with different socio-economic and environmental development characteristics or residents with representative characteristics to estimate a more comprehensive VSL.
Acknowledgements

This work was jointly funded by National Natural Science Foundation of China (NO.71773061), National Key R&D Program of China (2017YFA0603602), Delos China (HK) Limited and Cyrus Tang Foundation. We thank Huan Cai from Shantou University, Qiaoyang Lai from Shantou University, Kun Wang from Jiangxi University of Science and Technology, Menqiu Lu from Jiangxi University of Science and Technology, Ya Shi from Shanxi University, Min Zhang from Shanxi University, Binxian Gu from Yangzhou University, Hao Yu from Yangzhou University, Jie Song from Yangzhou University, and Jingsi Shi from Haibo Consulting for their contribution to this work.

Conflict of Interest

The authors declared that they have no conflicts of interest to this work.
References

Akhtar, S., Saleem, W., Nadeem, V., Shahid, I., Ikram, A., 2017. Assessment of willingness to pay for improved air quality using contingent valuation method. 

Alberini, A., Cropper, M., Fu, T.-T., Krupnick, A., Liu, J.-T., Shaw, D., Harrington, W., 1997. Valuing health effects of air pollution in developing countries: the case of Taiwan. Journal of environmental economics and management 34, 107-126. 

Alberini, A., Cropper, M., Krupnick, A., Simon, N.B., 2004. Does the value of a statistical life vary with age and health status? Evidence from the US and Canada. Journal of Environmental Economics and Management 48, 769-792. 

Arrow, K., Solow, R., Portney, P.R., Leamer, E.E., Radner, R., Schuman, H., 1993. Report of the NOAA panel on contingent valuation. Federal register 58, 4601-4614. 

Carson, R.T., Mitchell, R.C., Hanemann, M., Kopp, R.J., Presser, S., Ruud, P.A., 2003. Contingent valuation and lost passive use: damages from the Exxon Valdez oil spill. Environmental and resource economics 25, 257-286. 

EPA, 2015. Promoting the Use of Health Impact Assessment to Address Human Health in Reviews Conducted Pursuant to the National Environmental Policy Act and Section 309 of the Clean Air Act, WASHINGTON, D.C. 

Guo, X., Haab, T.C., Hammitt, J.K., 2006. Contingent valuation and the economic value of air-pollution-related health risks in China. 

Hammitt, J.K., Zhou, Y., 2006. The economic value of air-pollution-related health risks in China: a contingent valuation study. Environmental and Resource Economics 33, 399-423. 

Hanemann, M., Loomis, J., Kanninen, B., 1991. Statistical efficiency of double-bounded dichotomous choice contingent valuation. American journal of agricultural economics 73, 1255-1263. 

He, J., Wang, H., 2010. The value of statistical life: a contingent investigation in China. The World Bank. 

Hoffmann, S., Krupnick, A., Qin, P., 2017. Building a Set of Internationally Comparable Value of Statistical Life Studies: Estimates of Chinese Willingness to Pay to Reduce Mortality Risk. Journal of Benefit-Cost Analysis 8, 1-39. 

Hoffmann, S., Qin, P., Krupnick, A., Badrakh, B., Batbaatar, S., Altangerel, E., Sereeet, L., 2012. The willingness to pay for mortality risk reductions in Mongolia. Resource and Energy Economics 34, 493-513. 

Hu, D., Martin, C., Dredze, M., Broniatowski, D.A., 2020. Chinese social media suggest decreased vaccine acceptance in China: An observational study on Weibo following the 2018 Changchun Changsheng vaccine incident. Vaccine 38, 2764-2770. 

Istamto, T., Houthuijs, D., Lebret, E., 2014. Willingness to pay to avoid health risks from road-traffic-related air pollution and noise across five countries. Science of the total environment 497, 420-429. 

Kanninen, B.J., 1993. Optimal experimental design for double-bounded dichotomous choice contingent valuation. Land Economics, 138-146. 

Lancet, T., 2018. Vaccine scandal and confidence crisis in China. Lancet (London, England) 392, 360. 

Mitchell, R.C., Carson, R.T., Carson, R.T., 1989. Using surveys to value public goods: the contingent valuation method. Resources for the Future. 

Oriordan, T., Cummings, R.G., Brookshire, D.S., Schultze, W.D., 1987. Valuing Environmental Goods: An Assessment of the Contingent Valuation Method. Economic Geography 63, 358. 

Sun, C., Yuan, X., Xu, M., 2016. The public perceptions and willingness to pay: from the perspective of
the smog crisis in China. Journal of cleaner production 112, 1635-1644.
Venkatachalam, L., 2004. The contingent valuation method: a review. Environmental Impact Assessment Review 24, 89-124.
Viscusi, W.K., Aldy, J.E., 2003. The value of a statistical life: a critical review of market estimates throughout the world. Journal of risk and uncertainty 27, 5-76.
Wang, H., Mullahy, J., 2006. Willingness to pay for reducing fatal risk by improving air quality: a contingent valuation study in Chongqing, China. Science of the Total Environment 367, 50-57.
Wang, K., Wu, J., Wang, R., Yang, Y., Chen, R., Maddock, J.E., Lu, Y., 2015. Analysis of residents' willingness to pay to reduce air pollution to improve children's health in community and hospital settings in Shanghai, China. Science of the Total Environment 533, 283-289.
Wang, Y., Zhang, Y.-S., 2009. Air quality assessment by contingent valuation in Ji'nan, China. Journal of environmental management 90, 1022-1029.
Wei, W., Wu, Y., 2017. Willingness to pay to control PM2.5 pollution in Jing-Jin-Ji Region, China. Applied Economics Letters 24, 753-761.
Yang, Z.-f., Xu, L.-y., 2004. Valuing health effects from the industrial air pollution in rural Tianjin, China. Journal of Environmental Sciences 16, 157-160.
Yin, H., Pizzol, M., Jacobsen, J.B., Xu, L., 2018. Contingent valuation of health and mood impacts of PM2.5 in Beijing, China. Science of the Total Environment 630, 1269-1282.
Zhang, X., 2002. Valuing mortality risk reductions using the contingent valuation methods: evidence from a survey of Beijing Residents in 1999. Centre for Environment and Development, Chinese Academy of Social Sciences, Beijing, China.
Figures

Figure 1
The distribution curves of WTP in six research cities

Supplementary Files
This is a list of supplementary files associated with this preprint. Click to download.

- SupplementalInformationVSLinChina.pdf