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Valuing mortality risk in China: Comparing stated-preference estimates from 2005 and 2016

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Abstract

We estimate the marginal rate of substitution of income for reduction in current annual mortality risk (the "value per statistical life" or VSL) using stated-preference surveys administered to independent samples of the general population of Chengdu, China in 2005 and 2016. We evaluate the quality of estimates by the theoretical criteria that willingness to pay (WTP) for risk reduction should be strictly positive and nearly proportional to the magnitude of the risk reduction (evaluated by comparing answers between respondents) and test the effect of excluding respondents whose answers violate these criteria. For subsamples of respondents that satisfy the criteria, point estimates of the sensitivity of WTP to risk reduction are consistent with theory and yield estimates of VSL that are two to three times larger than estimated using the full samples. Between 2005 and 2016, estimated VSL increased sharply, from about 22,000 USD in 2005 to 550,000 USD in 2016. Income also increased substantially over this period. Attributing the change in VSL solely to the change in real income implies an income elasticity of about 3.0. Our results suggest that estimates of VSL from stated-preference studies in which WTP is not close to proportionate to the stated risk reduction may be biased downward by a factor of two or more, and that VSL is likely to grow rapidly in a population with strong economic growth, which implies that environmental-health, safety, and other policies should become increasingly protective.

Keywords Value of statistical life · Stated preference · Willingness to pay · China

JEL Classifications D61 · H43 · I18 · Q51

1 Introduction

The value per statistical life (VSL) is a measure of the monetary value of reducing mortality risk in a specified period, which is widely used in economic evaluation of

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environmental-health and safety policies. There exist many studies estimating VSL in the United States and several other high-income countries, but relatively few studies in low- and middle-income countries (Robinson et al. 2019). VSL is defined for an individual and is likely to depend on characteristics of the individual and her environment, including income, age, life expectancy, health, and social-support networks (Hammitt 2017). The link with income is perhaps the clearest and best studied. Both theory and empirical evidence suggest that VSL is positively associated with income but estimates of the magnitude of the effect vary widely. Moreover, the magnitude may differ between cross-sectional comparisons within a national population or between countries, and intertemporal comparisons within a population that becomes wealthier over time. If income in a population is anticipated to increase over time, environmental-health and safety regulations should become increasingly stringent and the present value of future mortality-risk reductions decreases with time more slowly than the discount rate.

This study presents estimates from two stated-preference surveys of the general population in Chengdu, China conducted using similar methods in 2005 (Guo 2006) and 2016. These surveys provide information about VSL in a large Chinese city and about how VSL changed over a period of rapid economic growth.

Estimates of the income elasticity of VSL are frequently used to calculate the value of environmental and other interventions that are anticipated to yield persistent reductions in mortality risk. This practice is of long standing: the 1987 regulatory impact analysis for the U.S. regulations implementing the Montreal Protocol (which restricted use of CFCs and other stratospheric-ozone-depleting compounds) valued future reductions in skin-cancer-related mortality risk assuming the income elasticity of VSL is one in the base case, with alternative values of one-half and two in sensitivity analyses (measuring income as GDP per capita; Hammitt 1997).

Most estimates of the income elasticity of VSL come from one of two sources: direct estimates of how VSL varies with income in stated-preference studies (e.g., based on the estimated coefficient on income in a cross-sectional regression) and comparison or meta-analyses of estimates of VSL from compensating-wage-differential studies[1] (e.g., Viscusi and Aldy 2003; Viscusi and Masterman 2017). Most of these studies yield estimates of approximately one or smaller, though comparisons of estimates between countries with widely different incomes often yield estimates larger than one (Hammitt and Robinson 2011).

Here we employ a third approach, comparison of estimates from a population at different points in time. We are aware of only two previous applications of this approach, both using compensating-wage differentials. Hammitt et al. (2000) estimated wage differentials using annual data for each year from 1982 to 1997 in Taiwan, when real GNP per capita grew by a factor of about 2.5. They estimated income elasticities between about 2.0 and 3.0. Costa and Kahn (2004) estimated wage differentials each decade from 1940 to 1980 for U.S. workers and estimated an income elasticity of 1.5 to 2.0 (using GNP per capita as a measure of income).

[1] Compensating-wage-differential studies regress wage on occupational fatality risk; because wages are highly correlated with income, it is difficult to estimate the effect of income directly, though Evans and Schaur (2010) and Kniesner et al. (2010) use quantile regression to estimate how VSL differs across the wage distribution. Stated-preference studies have also been evaluated using meta-analysis (e.g., Lindhjem et al. 2011; Masterman and Viscusi 2018).

A challenge in using stated preferences to estimate VSL is that a survey respondent may have limited understanding of the magnitude of a small change in her probability of death within the stated period and little idea of its value relative to other goods and services her money can buy. A common validity test is to compare respondents' compensating surplus or willingness to pay (WTP) for different risk reductions. "Internal" tests compare individuals' valuations for multiple risk reductions; "external" tests compare different individuals' valuations for different (randomly assigned) risk reductions. Under conventional theory, an individual's WTP to reduce current mortality risk by a small amount should be less than but close to proportional to the magnitude of the risk reduction. Yet many studies find that WTP varies much less than in proportion to risk reduction; e.g., Hammitt and Graham (1999) report that WTP is statistically significantly related to risk reduction in 11 of 14 studies, but never close to proportional; Lindhjem et al. (2011) report in their meta-analysis of approximately 850 VSL estimates that the estimated elasticity of VSL with respect to risk reduction is between −0.25 and − 0.83, even in restricted subsamples, which implies the elasticity of WTP with respect to risk reduction is between 0.75 and 0.17. This is an example of the problem of insensitivity (or inadequate sensitivity) to scope often found with stated-preference surveys.

One response to the problem of inadequate sensitivity is to use visual aids or other methods to help communicate the magnitude of risk changes to respondents; Corso et al. (2001) showed that respondents presented with either a field of dots (where the fraction corresponding to the probability was distinctively colored) or a risk ladder (displaying different causes of fatality with their actuarial frequency) exhibited appropriate sensitivity to scope while a control group that was not presented with any visual aid did not. Another approach is to investigate heterogeneity among respondents to identify those who apparently fail to understand the questions or who respond in a manner that does not reveal their WTP (e.g., individuals who respond that they would not be willing to pay any positive amount as a protest against some aspect of the scenario). For example, Krupnick et al. (2002) tested the effect of excluding respondents who failed tests of comprehension (such as identifying the larger of two probabilities) or of scenario acceptance (such as disbelieving the stated risk); Hammitt and Herrera-Araujo (2018) use latent class analysis to differentially weight respondents whose answers are more consistent with validity criteria.

In this paper, we identify subsamples of respondents whose answers exhibit consistency with theoretical conditions: WTP should be strictly positive and nearly proportional to the magnitude of the risk reduction. We find that responses from these subsamples are consistent with theoretical predictions and that estimated VSL is larger for these subsamples than for the full sample. Moreover, we find a dramatic increase in estimated VSL between the two surveys; VSL for the average respondent increased by a factor of roughly 25 between 2005 and 2016, much more than the approximately threefold increase in median income. Attributing the entire increase in VSL to the change in real income (neglecting changes in other factors) implies an income elasticity of 3.0.

The remainder of the paper is organized as follows. Section 2 describes the theoretical model of WTP for a reduction in current mortality risk and derives the conditions we use to identify respondents whose answers can be interpreted as consistent with the economic model. Section 3 provides information about our survey site, Chengdu, and describes the survey and data-collection procedures. Section 4 provides results, including descriptive statistics and alternative statistical models to estimate VSL. Section 5 concludes.

2 Consistency test

Our consistency test incorporates two components: positivity (elicited WTP must be strictly positive) and proportionality (WTP for two risk reductions must be less than but close to proportional to the magnitudes of the risk reductions).[2] We elicit WTP to reduce current-year mortality risk using binary-choice questions. Binary-choice questions are incentive-compatible (because truth telling is a dominant strategy) and are cognitively easier than open-ended questions that ask a respondent to state her maximum WTP. A disadvantage is that binary-choice questions provide only bounds on the respondent's WTP. If a respondent indicates she would purchase the risk reduction at a stated price, the price is a lower bound on her WTP; if she indicates she would not purchase it, the price is an upper bound.

In our 2016 survey, each respondent valued two risk reductions: in one, she was offered an intervention to reduce her risk of dying in the current year by 3/10,000 at a price P; in the other, the risk reduction was 5/10,000 and the price was (5/3) P. The order of questions was randomized; approximately half the respondents valued the smaller risk reduction first and half valued the larger risk reduction first. The price P was randomly varied among respondents. In our 2005 survey, each respondent valued only one of these risk reductions.

The proportionality component of our test is based on the result that, under conventional economic theory, WTP for a risk reduction of 5/10,000 should be slightly smaller than 5/3 as large as WTP for a risk reduction of 3/10,000. (The acceptable deviation from proportionality is quantified below.) Let WTP_3 and WTP_5 denote an individual's WTP for the 3/10,000 and 5/10,000 risk reductions, respectively. Response-pattern labels YY, NN, YN, and NY denote responses yes (would purchase the intervention) or no (would not purchase it) for the smaller and larger risk reductions, respectively, regardless of the order in which the questions were asked.

Two patterns of responses are clearly consistent with theory: YY ($WTP_3 > P$ and $WTP_5 > (5/3)\ P$) and NN ($WTP_3 < P$ and $WTP_5 < (5/3)\ P$). The pattern NY ($WTP_3 < P$ and $WTP_5 > (5/3)\ P$) implies that WTP is more than proportional to risk reduction, which violates conventional theory. The remaining pattern YN ($WTP_3 > P$ and $WTP_5 < (5/3)\ P$) is consistent with theory if WTP_3 and WTP_5 are sufficiently close to P and (5/3) P, respectively, and inconsistent otherwise. We classify individuals whose responses fit this pattern as failing to satisfy our test. Hence, only respondents whose answers exhibit the YY or NN pattern satisfy the proportionality component of our consistency test.[3]

An individual whose WTP is zero for both risk reductions will respond NN. Under conventional theory, WTP is strictly positive and hence a respondent who reports zero WTP reveals either preferences that are inconsistent with theory or rejection of the scenario provided in the survey. To identify these respondents, we ask respondents who report they would not accept the risk reduction at either of the positive prices offered to

[2] This two-part test was first applied by Alolayan et al. (2017) in a stated-preference study to estimate VSL in Kuwait.

[3] Note that consistency with theory is a sufficient but not necessary condition for responses YY or NN. For example, a respondent who values the two risk reductions equally (violating proportionality) would respond YY if the common value is greater than the prices offered for both risk reductions.

them whether they would accept it if it were free; individuals who reject a free risk reduction fail the positivity component of the consistency test.[4]

The logic of our consistency test is illustrated by Fig. 1. The figure shows an indifference curve between current-year income y and current-year survival probability s. VSL is defined as the marginal rate of substitution of y for s, i.e., (minus one times) the slope of the indifference curve. Beginning at the initial point (s_0, y_0), v_1 is the WTP to reduce risk by the amount r_1 ($= s_1 - s_0$). It satisfies

$$v_1 = r_1\ VSL_a \tag{1}$$

where VSL_a is minus the slope of the indifference curve somewhere between the initial point (s_0, y_0) and the terminal point (s_1, y_1). Similarly, v_2, the WTP for an additional risk reduction r_2, satisfies

$$v_2 = r_2\ VSL_b \tag{2}$$

where VSL_b is minus the slope of the indifference curve somewhere between (s_1, y_1) and (s_2, y_2).

The proportionality component of our test compares the ratio between WTP amounts for different risk reductions beginning at the same point with the ratio of risk reductions. Specifically, we compare the WTP ratio $V = (v_1 + v_2)/v_1 = 1 + v_2/v_1$ with the risk-reduction ratio $R = (r_1 + r_2)/r_1 = 1 + r_2/r_1$.

Substitution from eqs. (1) and (2) yields

$$V = 1 + \frac{v_2}{v_1} = 1 + \frac{r_2 VSL_b}{r_1 VSL_a}. \tag{3}$$

Under standard assumptions described below, the indifference curve in Fig. 1 is downward sloping and convex, and hence

$$\frac{VSL_2}{VSL_0} < \frac{VSL_b}{VSL_a} < 1, \tag{4}$$

which implies

$$1 + \frac{r_2}{r_1}\frac{VSL_2}{VSL_0} < V < 1 + \frac{r_2}{r_1} = R \tag{5}$$

where VSL_0 is VSL at the point (s_0, y_0) and VSL_2 is VSL at the point (s_2, y_2). The extent to which the WTP ratio V can differ from the risk-reduction ratio R depends on the ratio VSL_2/VSL_0.

The standard model for VSL assumes the individual seeks to maximize his expected indirect utility of income, where utility depends on whether he survives the current period or not. Specifically,

[4] In the 2016 survey, rejecting either risk reduction when it is free violates the criterion.

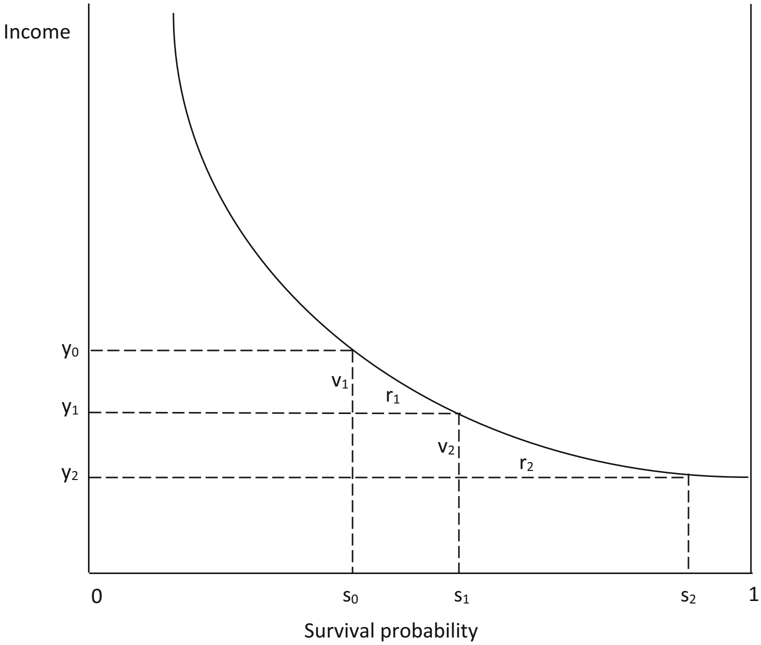

Fig. 1 WTP for increased survival probability

$$VSL = \frac{u_a(y) - u_d(y)}{s u_a'(y) + (1-s) u_d'(y)} \tag{6}$$

where $u_a(y)$ and $u_d(y)$ are the utility of income conditional on surviving and not surviving the current period, respectively, and primes denote derivatives. The standard assumptions are

$$u_a(y) > u_d(y) \tag{7a}$$

$$u_a'(y) > u_d'(y) \geq 0 \tag{7b}$$

$$u_a''(y) \leq 0, u_d''(y) \leq 0, \tag{7c}$$

i.e., survival is preferred to death, marginal utility of income is non-negative and strictly greater conditional on survival than on death (leaving income as a bequest), and weak risk aversion with respect to financial gambles conditional on survival and on death (Drèze 1962; Jones-Lee 1974; Weinstein et al. 1980). These assumptions imply that VSL decreases with survival probability and increases with income, and hence indifference curves are convex (as illustrated in Fig. 1).

To determine how much VSL_2 can differ from VSL_0, note that

$$VSL_2 = VSL_0 + (r_1 + r_2)\frac{\partial VSL}{ds} - (v_1 + v_2)\frac{\partial VSL}{dy} \tag{8}$$

where the two partial derivatives are evaluated at points (not necessarily the same) somewhere between (s_0, y_0) and (s_2, y_2). Hence VSL_2 is equal to VSL_0 plus an effect due to the increase in survival probability and an effect due to the reduction in disposable income.

From eq. (6) and assumption (7b), the effect of the difference in risk is largest when $u_d'(y) = 0$. In this case, the increase in survival probability from s_0 to s_2 decreases VSL (at any income y) by the factor

$$\frac{s_0}{s_2} = \frac{s_0}{s_0 + r_1 + r_2}. \tag{9}$$

In our survey, respondents are told their baseline mortality risk $(1 - s_0)$ is 15/10,000, 60/10,000, or 500/10,000 (for respondents aged 40 or younger, 41 to 65, and more than 65 years, respectively) and $r_1 + r_2 = 5/10{,}000$. These imply s_0/s_2 is between 9985/9990 and 9500/9505, and hence the effect of risk on VSL is negligible.

Theory provides less guidance about the effect of income on VSL. As described in Section 1, empirical estimates of the income elasticity of VSL range from less than 1 to 2 or slightly larger (Hammitt and Robinson 2011), with recent meta-analyses suggesting values from about 0.5 for the US to 1 or 1.1 for lower-income countries (Viscusi and Masterman 2017; Masterman and Viscusi 2018).

The proportional effect of the difference in income on VSL can be estimated as

$$\left(\frac{y_2}{y_0}\right)^{\eta} = \left(\frac{y_0 - v_1 - v_2}{y_0}\right)^{\eta} = Y^{\eta} \tag{10}$$

where η is the average income elasticity over the range (y_0, y_2) and Y is the net-income ratio y_2/y_0. In our sample, the median value of $v_1 + v_2$ is ~60 RMB (2005 sample) and ~1600 RMB (2016 sample) and the median annual incomes are ~10,000 RMB (2005 sample) and ~36,000 RMB (2016 sample).[5] Using these values, $Y \approx 0.99$ (2005) and 0.96 (2016) and so the effect of income is to reduce VSL by a factor no smaller than 0.92 for an income elasticity no greater than 2.

Combining the estimated effects of survival probability and income suggests that if WTP for a 3/10,000 risk reduction is exactly P, then WTP for a 5/10,000 risk reduction must be between 1.67 P and 1.53 P. While some of the respondents whose responses fit the pattern YN might have WTP values that fit this narrow window, it seems unlikely that many do. These bounds imply that the ratio of estimates of VSL obtained by dividing estimated WTP by the corresponding risk reduction should differ by a factor between about 1 and 1.09 (= 1/0.92).

[5] The exchange rate we use for both years is 7 RMB to 1 USD.

3 Survey instrument & administration

Our sample site, Chengdu, is the capital of Sichuan Province and one of the largest and most rapidly developing cities in western China. It is located on a plain about 500 m above sea level with mountains to the west and north; the climate is humid sub-tropical. Chengdu is an administrative region extending beyond the urban center itself, with a total resident population officially reported by statistical authorities as 16 million in 2016, including as many as 6.3 million migrants lacking local residence permits (*hukou*) described as the "floating population" (Chengdu Bureau of Statistics 2017); the total resident population of the nine primary urban districts is reported as 8.7 million in 2016 (Statistical Bureau of Sichuan and National Bureau of Statistics 2017).[6] Chengdu is a commercial, cultural, and communication center and the site of a giant-panda preservation institute. Between 1949 and 2011, the built-up area of the central city expanded from 18 to 354 km^2. Since 2003, Chengdu has been a pioneer in coordinated urban-rural development. It ranks high on livability among Chinese cities. Urban redevelopment has transformed the historical urban center from low-density, low-rise to high-density, high-rise construction in the last decade (Guan et al. 2019).

Data were collected by in-person interview of randomly selected residents in 2005 and 2016. The two samples were drawn independently, hence we cannot identify any individuals who may have been sampled in both periods. Any overlap is likely to be negligible.

The target population includes adults of Chinese nationality between the ages of 18 and 70 who had resided in Chengdu municipal districts (Jinjiang, Qingyang, Jinniu, Chenghua and Wuhou) for more than one year, without regard to official residency status. Sampling was conducted using a GPS/GIS assisted area sampling method (Landry and Shen 2005) by the Research Center for Contemporary China (RCCC) at Peking University. Unlike traditional survey methods based on registration lists, this method allows for inclusion of residents who are not registered urban residents.

Primary sampling units (one half degree square) were selected with probabilities proportional to population, from which secondary sampling units (90 m square) were randomly selected. Fieldworkers enumerated all the dwelling units in each secondary sampling unit, after which 30–60 dwelling units were selected from each unit (with equal probabilities across dwelling units in the secondary sampling units). Interviewers randomly selected one among all eligible residents of each selected dwelling unit. If the selected respondent was unavailable, the interviewer attempted to schedule a follow-up visit; five callbacks by multiple interviewers were required before classifying a selected respondent as a refusal. At least 20% of completed interviews by each interviewer were verified by supervisors who revisited the dwelling unit or confirmed responses by telephone. Completed interviews were obtained from 997 of about 1400 eligible respondents (71%) in 2005 and 1051 of 1602 eligible respondents (66%) in 2016.

[6] Official population statistics for Chinese cities are notoriously difficult to cite and often conflicting in the literature because of: 1) varying use of terms, including the names of cities themselves, which can refer to the central urban jurisdiction or administrative regions that also include satellite cities, towns, and large rural areas; 2) conflicting categorizations, including two different terms generally translated into English as "urban"; and 3) focus of the census authorities on total residents and those with local residence permits (even if they live elsewhere), while non-registered migrant residents (who are generally poorer) are estimated separately by the Public Security Bureau using different methods.

The survey instrument was similar in both periods. It began with questions about standard demographics (birth year, duration of residence in Chengdu, urban or rural resident registration, and highest completed level of education). These were followed by questions about current health status and health behaviors including smoking, regular exercise, and health insurance coverage. The following section contained questions about asthma in 2016, and about asthma and chronic bronchitis in 2005. Respondents who had not been diagnosed with these conditions were asked about their WTP to reduce the chance of developing it; respondents who had been diagnosed were asked about their WTP to reduce the severity of their condition. The next section included questions about WTP to reduce mortality risk (described below). It was followed by questions about employment status and history (type of work and employer), and personal and household income.

In the mortality-valuation section, the respondent was told the chance of dying in the current year for someone of her age (15, 60, and 500 per 10,000 for ages 40 and younger, 41 to 60, and older than 60 years, respectively). In the 2016 survey, WTP was elicited for two risk reductions, of 3/10,000 and 5/10,000 (in random order). In the 2005 survey, WTP was elicited for only one of the two risk reductions (randomly selected).[7] The risk reductions are small compared with baseline mortality (especially for older individuals) so it is plausible to believe they might be achievable. To help respondents evaluate the magnitude of the risk reduction, they were told the initial and final risk, the risk reduction, and the expected decrease in the number of deaths if all adults in urban Chengdu benefited from the risk reduction.

The risk reduction was described as produced by "a preventive and painless treatment that would reduce the risk that one would die during the next year" that could be obtained from a reputable hospital near the respondent's home. The treatment would have no side effects, would be effective for one year, and the respondent would have to pay the cost directly (it would not be covered by health insurance or other sources).

The elicitation questions follow the standard double-bounded dichotomous-choice format (Hanemann et al. 1991): the respondent was first asked if she would accept the treatment if the cost were X. If the response was yes, she was then asked if she would accept the treatment if the cost were Y ($Y > X$); if the response was no, she was asked if she would accept the treatment if the cost were Z ($Z < Y$). If that response was no, the respondent was asked if she would accept the treatment if it were free.

Assuming accurate answers, these questions provide bounds on the individual's WTP, of 0 and Z for an individual who responds no to both binary-choice questions (and yes to the free treatment), Z and X for an individual who responds no to the first and yes to the second question, X and Y for an individual who responds yes to the first and no to the second question, and only a lower bound (Y) for an individual who responds yes to both the first and second questions. Respondents who report they would not accept the treatment if it were free have WTP less than or equal to zero,

[7] The 2005 survey also elicited WTP for a risk reduction of 10/10,000 from one-third of the respondents. These respondents are excluded from our analysis because if elicited WTP is less than proportional to risk reduction, including them could lead to lower estimates of VSL, biasing upward the observed change in VSL between the two periods. We report below the effect on estimated VSL if these respondents are included.

perhaps because they believe the treatment would not work, would have other drawbacks, or reject the scenario for other reasons.

In the 2016 survey, the initial bid (X) for the question about the larger risk reduction (5/10,000) was 5/3 as large as the initial bid for the question about the smaller risk reduction (3/10,000). In the 2005 survey, a common set of bids was used for both risk reductions.

For both the 2005 and 2016 surveys, we identify a restricted subsample consisting of respondents who satisfy the positivity component of our validity test (i.e., excluding respondents who answered no to the questions about accepting the treatment at prices X, Y, and zero).[8] For the 2016 survey, we identify a second restricted sample consisting of respondents who satisfy both the positivity and proportionality components (i.e., those who respond yes to the initial bid X in both valuation questions, or who respond no to both initial bids).

4 Results

Descriptive statistics for the full samples and the restricted subsamples are presented in Table 1. A total of 671[9] respondents completed interviews in 2005 and 1051 in 2016. In the earlier sample, 72% of respondents (480/671) reported a positive WTP for the mortality risk reduction; in the later sample, only 52% reported positive WTP (551/1051). The fraction of 2016 respondents whose answers to the two mortality-valuation questions also satisfy the proportionality criterion is 42% (440/1051).[10] Although large fractions of respondents are excluded from the restricted subsamples, the distributions of individual characteristics are not very different from the full samples (as shown in Table 1). In both periods, the subsamples have somewhat more education than the full sample. In 2016, the subsamples have higher income and a larger fraction who exercise more than seven hours a week than the full sample. Mean household size is similar in the 2016 full sample and the subsample that satisfies the positivity and proportionality components (3.1 to 3.2), but it is much smaller in the subsample that satisfies only positivity (2.1). Regression models estimated to identify individual characteristics that predict whether an individual satisfies the validity criteria reveal no strong and statistically significant predictors.

Some characteristics of the 2005 and 2016 samples differ substantially, reflecting rapid change over that period. Mean age increased from about 39 to 43 years and the fraction currently married increased from 66 to 73%. The fraction of respondents having health insurance increased from 62 to 80%. Surprisingly, the gender composition of the sample shifted dramatically, from 39 to 50% female.

Personal income increased greatly. Among respondents who answered the income question, the fraction who reported income of less than 1000 RMB per month decreased from 54 to 28% and the fraction reporting 3000 RMB per month or more increased from 7 to 44%. Median annual income, estimated by linear interpolation

[8] For the 2016 survey, a respondent who rejects at least one of the treatments when it is free is classified as failing the positivity criterion.

[9] An additional 322 respondents valued a larger risk reduction (10/10,000) and are excluded from the analysis.

[10] Of the 111 respondents with WTP > 0 excluded by the proportionality test, 71 (64%) responded YN and 40 (36%) responded NY to the smaller and larger risk reductions, respectively.

Table 1 Descriptive statistics (mean and standard deviation)

		2005		2016		
		Full sample	WTP > 0	Full sample	WTP > 0	Consistent
Sample size		671	480	1051	551	440
Age		39.3 (14.34)	38.4 (14.42)	43.1 (15.2)	41.3 (14.9)	41.5 (15.0)
Female		0.393	0.425	0.499	0.479	0.475
Married		0.656	0.635	0.725	0.719	0.734
Household size		2.97 (1.18)	2.95 (1.16)	3.16 (1.34)	2.14 (1.40)	3.14 (1.34)
Income	0 (no income)	0.156	0.156	0.182	0.163	0.170
(RMB/month)	1–999	0.338	0.348	0.012	0.004	0.005
	1000 - 2999	0.343	0.340	0.204	0.172	0.177
	3000 - 4999	0.037	0.040	0.209	0.238	0.241
	5000 - 7999	0.019	0.010	0.070	0.082	0.082
	≥ 8000	0.006	0.004	0.028	0.029	0.027
	No answer	0.100	0.102	0.295	0.312	0.298
Median income (RMB/yr)		10,420	10,100	30,650	36,500	35,860
Health insurance		0.624	0.667	0.807	0.822	0.805
Education	≤ primary school	0.159	0.125	0.251	0.199	0.214
	middle to professional school	0.613	0.633	0.628	0.652	0.639
	≥ college	0.228	0.242	0.121	0.151	0.148
Current health	excellent	0.039	0.038	0.053	0.076	0.073
	very good	0.361	0.377	0.347	0.361	0.352
	good	0.353	0.346	0.346	0.341	0.348
	fair	0.218	0.206	0.205	0.180	0.186
	poor	0.030	0.033	0.049	0.042	0.041
Current smoker		0.382	0.350	0.356	0.368	0.375
Exercise >7 h/week		0.238	0.254	0.386	0.430	0.420
Urban residential registration		0.730	0.746	0.582	0.590	0.589

Median income linearly interpolated from monthly income categories and multiplied by 12 months/yr.

within bins and multiplying monthly income by 12, increased from about 10,420 RMB to 30,650 RMB.[11]

Education decreased, e.g., the fraction having only primary education or less increased from 16 to 25% and the fraction having graduated college decreased from 23 to 12%. This may be explained by an influx of rural immigrants, as the fraction of respondents whose residential registration is urban decreased from 73 to 58%. Self-reported health was little changed although the fraction who reported exercising seven hours per week or more increased from 24 to 39% and the fraction of respondents who were smokers decreased slightly (from 38 to 36%).

[11] Income statistics are calculated excluding individuals who declined to answer. For comparison, GNI per capita in China was 14,300 RMB in 2005 and 53,800 RMB in 2016 the estimated median incomes are 73% and 57% of these values, respectively. The CPI increased by a factor of 1.36 over the period (https://data.worldbank.org/).

Table 2 reports the fraction of respondents who reported they would purchase the risk reduction at the initial bid (stated price) as a function of the bid and risk reduction. These results satisfy basic validity criteria. For both years and both risk reductions, the fraction accepting the bid is a decreasing function of the bid. For the 2005 survey the fraction accepting each bid is (weakly) larger for the larger than the smaller risk reduction.[12] For the 2016 survey the fraction accepting a bid of (5/3) P for the larger risk reduction is close to but generally smaller than the fraction accepting a bid of P for the smaller risk reduction, consistent with near proportionality of WTP to risk reduction.

Turnbull lower-bound-mean estimates of VSL are also reported in Table 2. For the 2005 sample, the lower-bound estimates are about 11,000 and 13,000 USD for the smaller and larger risk reductions; for the 2016 sample, they are about 360,000 and 330,000, respectively. Within each year, the estimates of VSL from the two risk reductions are reasonably similar; between years, there is a large increase.

Table 3 reports estimates of our simple regression model. We estimate

$$log(WTP_i) = \alpha + \beta log(r_i) + \varepsilon_i, \tag{11}$$

where WTP_i is individual i's WTP, r_i is the risk reduction and ε_i is a residual, assumed to be normally distributed with mean zero. The dependent variable is interval-censored with lower bound equal to the largest bid at which the individual reported she would choose the risk reduction (zero if she rejected the risk reduction at each positive bid) and upper bound equal to the smallest bid at which she reported she would reject the risk reduction (or unbounded if she accepted the risk reduction at both bids). Equation (11) is estimated by maximum-likelihood methods (Alberini 1995).

Recall from Section 2 that the ratio of WTP for the large risk reduction to WTP for the small risk reduction should be close to the ratio of risk reductions (5/3) and should be no smaller than 0.92 times this ratio (if the income elasticity is no larger than 2). These bounds imply the coefficient on the log of the risk reduction (β) should be less than one and no smaller than log(0.92 • 5/3) / log(5/3) ≈ 0.83.

Respondents in the 2005 sample were asked about only one mortality-risk reduction. The estimated value of β is about 0.51 in the full sample and 0.84 in the subsample restricted to respondents who satisfy the positivity component. The estimate for the restricted subsample is significantly greater than zero and is between the theoretical bounds (0.83 and 1), satisfying the proportionality component of our validity test. In contrast, the estimate for the full sample is somewhat smaller and is not significantly different from zero, 0.83, or one. For the full sample, we cannot reject the hypothesis that WTP is insensitive to risk reduction ($\beta = 0$) nor that WTP satisfies the proportionality criterion ($0.83 < \beta < 1$); but with an estimated standard error of 0.43, we have little power to discriminate between these hypotheses.

For the 2016 survey, we estimate the simple regression model for the full sample, the subsample that satisfies the positivity criterion, and the "consistent" subsample that satisfies both the positivity and proportionality criteria. Although each respondent valued two risk reductions, the regression estimates use answers only to the question

[12] For the 2016 survey, only one bid (1500 RMB) is used for both risk reductions; the fraction accepting that bid is larger for the larger than the smaller risk reduction.

Table 2 Responses to initial bids and Turnbull lower-bound estimates of VSL

Risk reduction = 3/10,000			Risk reduction = 5/10,000		
Bid (RMB)	N	Yes (%)	Bid (RMB)	N	Yes (%)
2005 data					
5	142	74	5	109	76
15	121	64	15	86	64
40	62	48	40	48	58
100	1	0	100	102	36
Turnbull lower bound					
WTP (RMB)	22.2		46.6		
VSL (USD)	10,600		13,300		
2016 data					
300	131	63	500	134	51
900	133	32	1500	130	32
1500	133	23	2500	130	16
3000	131	15	5000	129	16
Turnbull lower bound					
WTP (RMB)	751		1138		
VSL (USD)	357,000		325,000[a]		

Currency conversion: 7 RMB = 1 USD

a. Calculating assuming fraction(yes) = 0.16 for bids of 2500 and 5000 RMB. If these cells are pooled at bid = 2500 in accordance with pooled adjusted violators algorithm (Turnbull 1976), WTP = 731 and VSL = 209,000

Table 3 Simple regression model

	2005		2016		
	Full sample	WTP > 0	Full sample	WTP > 0	Consistent
Log (risk reduction)	0.513	0.836***	0.439*	0.593***	0.751***
	(0.428)	(0.323)	(0.256)	(0.215)	(0.288)
Intercept	7.252**	10.64***	9.644***	11.98***	13.27***
	(3.359)	(2.533)	(2.015)	(1.691)	(2.254)
Residual standard deviation	2.405***	1.433***	1.772***	1.149***	1.336***
	(0.148)	(0.0822)	(0.0829)	(0.0533)	(0.0797)
Log likelihood	−792.58	−488.28	−1170.70	−716.60	−538.22
Observations	671	480	1051	551	440
WTP (RMB)	25.49	60.29	497.3	1541	1626
VSL (USD)	9100	21,500	177,600	550,400	580,900
VSL / annual income	6.12	14.9	40.6	106	113

*, **, *** denote significantly different from zero at 10%, 5%, 1%, respectively. Currency conversion: 7 RMB = 1 USD

valuing the first risk reduction for each respondent; hence the estimates of β are identified by differences in WTP between respondents and correspond to an "external" (between-respondent) rather than an "internal" (within-respondent) test of scope sensitivity.

Estimates of β for the 2016 full sample, the subsample who report positive WTP, and the consistent subsample are 0.44, 0.59, and 0.75, respectively. All three are significantly different from zero. Although all three estimates are smaller than the theoretical lower bound (0.83), the hypothesis that $\beta \geq 0.83$ can be rejected for the full sample ($p = 0.06$) but not for the two restricted subsamples (the p-values are 0.14 and 0.39 for the WTP > 0 and consistent subsamples, respectively).

For both surveys, we find that the point estimate of sensitivity of WTP to risk reduction is larger in the restricted subsamples than in the full sample. The hypothesis that WTP increases nearly in proportion to risk reduction can be rejected for the 2016 full sample but not the 2005 full sample; it cannot be rejected for any of the restricted subsamples. Hence estimates from the subsamples do not violate implications of standard economic theory.

Estimates of WTP and VSL from the simple regression model are reported at the bottom of Table 3. WTP is calculated as the median value (over the error term) at the mean risk reduction; i.e., $\hat{WTP} = exp\left[\hat{\alpha} + \hat{\beta} log(4/10,000)\right]$. VSL is estimated as $\hat{WTP}$ divided by the risk reduction (4/10,000) and converted to US dollars using an exchange rate of 7 RMB to 1 USD. In both periods, estimated WTP and VSL are larger for the restricted subsamples than for the corresponding full sample, reflecting the larger estimated coefficient on risk reduction (and also the larger intercept) in the subsamples. For 2005, estimates from the restricted subsample are more than twice those from the full sample; for 2016 the difference is more than three-fold. In contrast, the 2016 estimates for the subsamples based on positivity and on both positivity and proportionality are similar, differing by less than 6%. The Turnbull lower-bound-mean estimates of VSL for the full samples (Table 2) are larger than the full-sample regression estimates but smaller than the regression estimates for the restricted subsamples for both years.[13]

Estimated WTP and VSL increased sharply between the two periods. Using the comparable subsamples (restricted to individuals with positive WTP), VSL is estimated as 21,500 USD in 2005 and 550,000 USD in 2016, a 25-fold increase. This change greatly exceeds the increase in median annual income, from 10,100 to 36,500 RMB for the corresponding subsamples, a factor smaller than four. As a result, the ratio of VSL to median annual income increased from about 15 to 110 between the two periods. If the increase in VSL is attributed solely to the change in real income, the implied elasticity is 3.0.[14,15]

[13] The Turnbull lower-bound means are non-parametric estimates of mean WTP; the estimates from the simple regression models are parametric estimates of the median WTP over the error term. Hence the parametric estimates can be smaller than the non-parametric lower bounds.

[0] This elasticity is calculated comparing estimates from the subsamples that satisfy the positivity criterion; using estimates from the full samples, the elasticity is 3.4.

[0] Including respondents to the 2005 survey who valued a larger risk reduction (10/10,000) has a modest downward effect on the estimated VSL. The estimated coefficients (standard errors) on log(risk reduction) are 0.633 (0.160) and 0.744 (0.120) for the full sample ($N = 993$) and the subsample with WTP > 0 ($N = 694$). The estimated intercepts (standard errors) are 8.147 (1.202) and 9.829 (0.897), respectively. VSLs calculated for a risk reduction of 4/10,000 are 8710 and 19,700 USD, respectively, about 4 and 9% smaller than the values in Table 3.

Table 4 reports estimates of regression models for the full samples and subsamples including additional covariates. Adding the covariates decreases the estimated sensitivity of WTP to risk reduction compared with the models in Table 3, though the effect is small (less than one-half standard error) in all cases except the 2005 full sample. The comprehensive models reveal only a modest number of statistically significant relationships. There is evidence that respondents with more education have larger WTP; this effect is larger in 2005 than in 2016 and is smaller in the subsamples than in the corresponding full samples. WTP is decreasing with age in the full samples but not in the restricted samples; the coefficient on age squared is never close to statistically significant. Respondents lacking health insurance have smaller WTP. Women have significantly smaller WTP than men in the 2016 subsamples, but not in 2005. The estimated coefficient on log income is small and never close to statistically significant.

Our estimates of VSL are broadly consistent with other estimates for low- and middle-income populations. Robinson et al. (2019) compared estimates of VSL in low- and middle-income countries with a proxy for income (GNI per capita). They identified 27 estimates, of which 12 yield VSL/income ratios of less than 20 or more than 300; they judged these estimates as implausible on the grounds that VSL should exceed the expected present value of lifetime consumption (assumed to be 20 times annual income) and that the ratio should not greatly exceed that for the United States, a high-income country with a large estimated ratio of VSL to income (160). The remaining 15 estimates yield ratios between about 25 and 160. Our estimate for 2005 (a ratio of 15 for the subsample that satisfies the positivity criterion) is toward the low end of the Robinson et al. sample (and less than their assumed lower bound of 20) and our estimate for 2016 (a ratio of about 110 for both restricted subsamples) is toward the higher end of the estimates they judge to be plausible.

5 Conclusions

This work has two objectives, methodological and substantive. The methodological objective is to evaluate whether stated-preference estimates of WTP to reduce current mortality risk that can be interpreted through the conventional economic model can be obtained by including only respondents whose answers to valuation questions satisfy basic consistency criteria. The criteria are that WTP is strictly positive and close to proportionate to risk reduction. The substantive objective is to estimate VSL in a large city in China and to evaluate how it changed over a period of rapid economic growth.

On the methodological objective, we find that estimates of the elasticity of WTP with respect to the stated risk reduction are consistent with theoretical criteria for subsamples of respondents who satisfy the validity tests. In contrast, the point estimates for the full sample are smaller than is consistent with theory; for the 2016 sample we can reject the hypothesis that the elasticity is as large as implied by theory but for the 2005 sample we cannot, possibly due to limited power. The estimated elasticity of WTP with respect to risk reduction is larger for the subsamples that satisfy the positivity criterion than for the full samples, and larger still for the subsample that satisfies both positivity and proportionality criteria. This suggests that estimates of WTP and VSL from the restricted subsamples are more plausible than those from the full samples.

Table 4 Comprehensive regression model

		2005		2016		
		Full sample	WTP > 0	Full sample	WTP > 0	Consistent
Log (risk reduction)		−0.127	0.696**	0.406	0.554***	0.734***
		(0.437)	(0.333)	(0.248)	(0.209)	(0.278)
Age – mean		−0.384**	−0.167	−0.152*	−0.0209	0.0318
		(0.171)	(0.128)	(0.0904)	(0.0819)	(0.110)
(Age – mean)^2		0.139	0.107	−0.0422	−0.0138	−0.0584
		(0.126)	(0.0951)	(0.0836)	(0.0693)	(0.0925)
Female		0.463*	0.00903	−0.207	−0.384***	−0.479***
		(0.275)	(0.210)	(0.165)	(0.139)	(0.185)
Married		0.342	0.368*	0.0930	0.0724	0.0919
		(0.278)	(0.211)	(0.176)	(0.148)	(0.202)
log (income)		−0.0398	−0.0197	0.00899	0.0171	0.0188
		(0.0431)	(0.0334)	(0.0229)	(0.0193)	(0.0251)
Income not reported		0.263	0.0947	0.233	0.208*	0.286*
		(0.355)	(0.278)	(0.144)	(0.120)	(0.162)
No health insurance		−0.492*	0.0146	−0.331*	−0.299**	−0.387**
		(0.253)	(0.197)	(0.177)	(0.153)	(0.194)
Education	≥ college	−0.145	0.203	0.537***	0.286*	0.256
		(0.298)	(0.238)	(0.201)	(0.162)	(0.217)
	≤ primary	−1.294***	−0.885***	−0.0580	0.153	0.205
		(0.326)	(0.249)	(0.185)	(0.162)	(0.207)
Health	≥ good	−0.154	−0.508	0.0778	−0.0805	−0.164
		(0.591)	(0.447)	(0.333)	(0.292)	(0.396)
	= fair	0.182	0.0427	−0.267	−0.346	−0.532
		(0.253)	(0.194)	(0.319)	(0.281)	(0.382)
Non-smoker		0.329	0.0247	0.0156	0.262*	0.349*
		(0.268)	(0.204)	(0.169)	(0.143)	(0.191)
Exercise <7 h/wk		−0.225	0.0826	−0.575***	−0.104	−0.123
		(0.261)	(0.196)	(0.136)	(0.115)	(0.153)
Urban residential registration		0.292	0.402*	0.135	0.226*	0.246
		(0.278)	(0.206)	(0.139)	(0.118)	(0.154)
Constant		1.955	8.977***	9.725***	11.60***	13.19***
		(3.491)	(2.663)	(1.988)	(1.673)	(2.223)
Residual standard deviation		2.263***	1.362***	1.688***	1.089***	1.254***
		(0.138)	(0.0780)	(0.0785)	(0.0505)	(0.0746)
Log likelihood		−761.81	−471.08	−1138.09	−695.12	−519.37
Observations		671	480	1051	551	440

*, **, *** denote significantly different from zero at 10%, 5%, 1%, respectively

Recall that the estimates of the elasticity of WTP with respect to risk reduction in the regression models are identified using between-respondent comparisons (they are "external" scope tests); within-respondent comparisons ("internal" scope tests) are used only to determine which respondents satisfy the proportionality criterion used to define the most restricted subsample.

Our results suggest: that the presence of respondents whose answers are inconsistent with standard theory is a contributor to findings of inadequate sensitivity to scope; that tests of consistency between responses and standard theory can be used to identify and exclude such respondents; and that estimates of VSL from the restricted subsamples are more credible than those from the full samples. The distributions of personal characteristics of respondents included in the restricted subsamples are not greatly different from those of the full samples, suggesting that the subsamples are broadly representative of the general population, and hence their WTP may provide a legitimate estimate of population WTP.

More broadly, these results suggest that estimates of VSL obtained from the many stated-preference studies in which WTP is substantially less than proportional to the stated risk reduction are biased downward (in our case, by factors of two to three). This might help explain why many stated-preference estimates of VSL are smaller than compensating-wage-differential estimates (Kochi et al. 2006), while stated-preference estimates that satisfy theoretical validity criteria are consistent with wage-differential estimates (Robinson and Hammitt 2016).

On the substantive objective, we find a large increase in VSL over the 11 years between surveys. Income grew rapidly, by a factor of three over the period, but VSL increased much more, growing by a factor of 25. If the change in real income is the only factor contributing to the change in VSL, the implied income elasticity is about 3.0, which is larger than many estimates but not unprecedented. Indeed, estimates obtained by the two previous studies that have investigated changes in VSL over time within national populations are also relatively large, approximately 2.0 to 3.0 (Hammitt et al. 2000) and 1.5 to 2.0 (Costa and Kahn 2004). The 2005 estimate (from the subsample that satisfies positivity) is about 15 times median income, which is small compared with estimates of VSL in other low- and middle-income populations. The 2016 estimates (from the subsamples) are about 110 times income, which is comparable to estimates obtained in some low- and middle-income populations and in the OECD (Robinson et al. 2019).

If the elasticity of VSL with respect to income is larger intertemporally than cross-sectionally, it may be that preferences for health and safety are socially influenced, and hence vary with population as well as individual characteristics. Alternatively, cross-sectional estimates of income elasticity may be biased downward if individual income is poorly measured, in part because respondents do not wish to reveal it (the fractions declining to report income in 2005 and 2016 were 10 and 30%, respectively). Another possibility is that the high estimates obtained by comparing populations over time are biased; as is well-known, correlations between group aggregates are not necessarily good estimates of individual correlations (this phenomenon is known as ecological inference/fallacy or Simpson's paradox, e.g., Robinson 1950; Freedman 2015).

Whatever its magnitude, a positive income elasticity of VSL implies that safety and environmental-health standards should become increasingly stringent when incomes are growing.[16] In China's occupational-health and safety realm, evidence of such increasing stringency is mixed. The two primary laws on workplace safety and prevention of occupational diseases have each been strengthened twice in the last

[16] The rapid income growth in Chengdu is characteristic of China overall; indeed GNI per capita has grown even more rapidly than personal income as measured in our survey.

decade, but enforcement is still believed to lag (Zhou 2018), with possible exceptions such as in the coal mining industry (Zhang et al. 2016).

In China's environmental realm, laws, regulations, and enforcement have developed considerably in recent years. The 2015 amendments to the bedrock Environmental Protection Law in China, for example, are seen as a legal breakthrough. They include a number of changes that strengthen standards and enforcement, such as greater public input (including public-interest lawsuits), centralizing monitoring and collection of discharge fees, charging violations per day rather than per incident (increasing their magnitude), and incorporating the principle that economic development should coordinate with environmental protection (Mu et al. 2014; Corne and Browaeys 2017). Strengthened enforcement of laws and standards affecting environmental health is evident in at least some high-profile areas, notably including control of industrial- and mobile-source air pollution emissions over the last decade resulting in reduced haze (Nielsen and Ho 2013; Silver et al. 2018). Exploding popular awareness of and concern about the health risks of air pollution after severe haze episodes in 2013, bolstered by newly public official monitoring data, are widely credited with driving particularly swift advances in both policy and enforcement over the last five years (Finamore 2018). Growing public interest and concern about environmental-health risks is consistent with the rapid increase in VSL we estimate.

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