PERCEIVED ARSENIC-RELATED MORTALITY RISKS FOR SMOKERS AND NON-SMOKERS

W. DOUGLASS SHAW, PAUL M. JAKUS and MARY RIDDEL*

Prolonged ingestion of arsenic in drinking water can increase the risks of dying of lung and bladder cancer, particularly for smokers. In a survey of arsenic hotspots in the United States, we elicited individuals’ subjective mortality risks related to the presence of arsenic in drinking water. Using this data, we address whether smokers perceive mortality risks from this source differently from non-smokers. We find that those who have smoked at some point in their life have significantly higher perceived arsenic mortality risks than those who have never smoked, on average. We also find that the sample group of current smokers has higher average perceived arsenic mortality risks than those who have quit smoking. We model the decision to treat water for arsenic and find some evidence that current smokers are less likely to engage in this mitigating behavior than are ex-smokers or non-smokers even though their perceived risk is higher. We infer that smokers are either less risk averse or have a higher rate of time preference than non-smokers and ex-smokers.

I. INTRODUCTION

Arsenic in drinking water can cause lung and bladder cancer and increase the risk of dying from either disease. The exact relationship between arsenic mortality risk and concentration levels is difficult to estimate with certainty, but the best current estimate places the risk for non-smokers at approximately 1 in 100 for U.S. households with high arsenic concentrations [50 parts per billion (ppb) or more] in their drinking water (NRC 2001). It is well known that smoking greatly increases the risk of dying from lung cancer (Samet 2001), but the mortality risk of lung or bladder cancer associated with exposure to high concentrations of arsenic is believed to double when the subject also smokes (NRC 2001; U.S. Environmental Protection Agency 2000). In this paper, we examine perceptions and averting behavior for the conditional mortality risk of drinking arsenic-contaminated water given that a subject smokes. In particular, we (1) explore the connection between perceived arsenic risk perceptions and smoking behavior and (2) examine the link between smoking status, exposure to arsenic in drinking water, perceived risk, and the decision to remove arsenic from drinking water.

Smokers’ risk preferences and perceptions have been a topic of considerable interest for at least 20 years (see, e.g., Slovic 2001; Viscusi 1990, 2002). Past research shows that smokers and non-smokers tend to display different risk.

2. Note that this paper does not address the probability an individual dies of lung cancer from smoking. Rather, we address the conditional probability that a person dies from lung cancer from arsenic exposure given they are a smoker.

ABBREVIATIONS

EU: Expected Utility
PPB: Arsenic Concentration
SEU: Subjected Expected Utility
STAR: Science to Achieve Results

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preferences as evidenced by choices made in the face of mortality risk (Hersch and Viscusi 1998; Khwaja, Sloan, and Salm 2006; Viscusi and Hersch 2001). These studies find that although smokers may differ from non-smokers in their preferences and/or estimated probabilities for risk, these authors caution against concluding that smokers have lower estimates of perceived risks than non-smokers. Our study makes two important contributions to this literature. First, we examine how smokers and non-smokers perceive risks of exposure to arsenic, which inflates the risk of lung and bladder cancer in smokers.

Studies that address the perception of conditional mortality risks are uncommon and we are not aware of any studies that elicit the conditional lung-cancer related risks associated with ingesting arsenic, given that a subject smokes. We find that on average, subjects underestimate risks from ingesting arsenic, even after reading an information booklet about the science of these risks. Still, we show that smokers, ex-smokers, and people who have never smoked understand the relative risks associated with arsenic exposure and smoking.

Second, perceived arsenic/smoking risks are used to explain differential water-treatment behavior on the part of smokers and non-smokers. We find that although smokers perceive greater risks from arsenic contamination than non-smokers, smokers are less likely to remove arsenic from their drinking water than non-smokers. When smokers—with greater perceived risk—fail to treat their drinking water, this may indeed provide support for the theories that higher rates of time preferences, or less health-risk aversion help explain individuals’ decisions to smoke. To proceed, the manuscript provides some background information on smoking, and risk perception in general, followed by a simple presentation of the underlying theory for our estimating equations. The fourth section briefly discusses the data, and the fifth and sixth split the discussion of the results into the perceived risk models, followed by the water-treatment model results, respectively. The final section offers some conclusions.

II. SOME BACKGROUND LITERATURE

A. Is Smoking Rational? Time Discounting and Risk Preferences

Rational addiction models of smoking counter the contention of Weinstein (1999) and other psychologists that smoking is inherently irrational and/or that smokers do not accurately perceive smoking-related risks. We note that a “rational” decision does not mean the decision results in something that is always inherently good for an individual, merely that she or he took in the best available information at the time, weighed costs and benefits of various actions, and chose an action that provided the highest perceived net benefit. Individuals regularly choose actions that can increase their risk of injury or death, at least in a long-run sense.

According to Becker and Murphy (1988), an addiction is rational if preferences are stable and both past and future consumption influence current consumption decisions. One outcome of Becker and Murphy’s model is that “present-oriented” individuals have more potential for addiction than “future-oriented” individuals. Using data from the National Health and Nutrition Examination Survey, Chaloupka (1991) finds some support for this hypothesis. He shows that smokers in the survey are not myopic, but concludes that younger smokers discount the future more heavily than older smokers. In a similar vein, Hammar and Johansson-Stenman (2004) find that smokers have a lower willingness to pay to reduce smoking risks than non-smokers do. They speculate that this may reflect their use of a higher discount rate for health risks relative to others.

Risk “preference” measures allow us to classify an individual according to the amount of risk she desires; when measured she can be classified as risk neutral, risk averse, or a risk loving. Risk preferences have been used to explain why people continue to smoke, even as smokers tend to overestimate smoking-related risks, that is, when smokers believe the health risk of smoking is even greater than scientists believe. Preferences for risk have been used to explain why smokers accept riskier jobs but receive less compensating pay than non-smokers, implying that smokers display less health-risk aversion than their non-smoking counterparts (Viscusi and Hersch 2001). More recently, Khwaja, Sloan, and Salm (2006) explore preferences for time and risk among smokers and non-smokers, finding that smokers are more risk tolerant. Their results also suggest that tolerance for risk is innate to the individual, and not caused by smoking. Taken together, the results of these studies imply that, relative to non-smokers, smokers may have a greater willingness to engage in other behaviors.
that may injure their health. According to this view then, risk preferences, rather than mis-calculated risk perceptions, explain smokers’ behavior regarding not only the decision to smoke but also other decisions that affect their health.

Smoking and Perceived Risk. Psychologists and economists have long-noted that the risk of an event, as perceived by a person, is often quite different from the risk as measured by epidemiological or actuarial studies (Arrow 1982). Perceived risk has been found to vary with several factors including income, household composition (number and age of children), education, gender, age, past experiences, and knowledge and understanding of science-based risks (Sjöberg 2000). Many studies have shown that on an average, women tend to report higher perceived risks than men (Dominitz and Manski 2007; Flynn, Slovic, and Mertz 1994; Slovic 2000b).

Sloan, Smith, and Taylor (2003) provide a thorough review of the voluminous literature on perceptions of smoking and other risks. It is quite common to find that smokers and non-smokers alike generally overestimate the risks of contracting lung cancer from smoking, as compared to what experts say are the actual risks. A typical method of eliciting risk is to ask a question such as: “Out of 100 people, how many smokers do you think will die of lung cancer?” Analyses of questions such as this have often indicated that smokers overestimate these mortality risks for an anonymous smoker. Overestimates of risk, as compared to statistical estimates for populations, have been found in numerous countries (see the pioneering study of Viscusi 1990, and Smith, Taylor, and Sloan 2001 and Sloan, Smith, and Taylor’s 2003 review of the literature).3

Researchers have elicited risk perceptions for many other health and environmental risks, often focusing on the delivery of information about a particular environmental risk. Some have concluded that risk communication can be effective, while others have found that even when one carefully communicates risks to people, the recipient of the information may not process it in a manner that leads to correspondence between science-based risk and perceived risk (Adler and Pittle 1984; Slovic, Fischoff, and Lichenstein 1985). Smith and Desvouges (1989) find significant differences in risk perceptions regarding radon-gas exposures depending upon the information they received and the manner in which it was presented. Differences in perceived risk are not limited to different informational treatments, however. Using a survey instrument that did not vary in informational content, Riddel and Shaw (2006) observe a great deal of variation in people’s perceived risks of transporting nuclear waste; the variation is attributed to gender, age, and whether or not the subject had health insurance.

III. THEORETICAL FRAMEWORK

Our theoretical model must explain the factors that influence a person’s subjective (perceived) risk associated with arsenic exposure, and then incorporate that risk into a model of consumer choice. Following the literature outlined in the previous section, a general model of perceived risk would include a measure of exposure to an environmental contaminant ($E$), a measure of information provided to people, such as scientists’ best estimate of risk at that exposure level ($p$), and other variables, such as demographic and health factors ($z$), that are believed to influence perceived risk. This may include smoking history, $S_m$. Perceived, or subjectively measured, risk, $s$, then, has been generally modeled as

$$s = s(E, p, S_m, z)$$

The expected utility (EU) model is the standard theoretical model of decision making under risk, and relies upon well-known science-based or technical probabilities of outcomes, $p$. For example, in a simple, two-outcome world of disease risk where utility depends on composite good $x$, expected utility is

$$EU = p \times U_1(x_1) + [1 - p] \times U_2(x_2)$$

where $U_i(\cdot)$ is the state-dependent utility function ($1 =$ develop disease, $2 =$ do not develop disease) and $x$ represents the composite good. Recall, however, that people act upon risks as
they perceive them, not necessarily as scientists measure the risk. Hence, the EU model must be extended to account for the fact that perceived risk, $s$, may differ from scientific risk, $p$. The perceived risk $s$ may in fact be dependent on individual-specific psychological, physical, and other factors as well as on $p$. In our case, a simple model of perceived risk would link the risk to some measure of exposure to the environmental contaminant (PPB, arsenic concentration), smoking history (Sm), and other demographic and health variables $z$. The EU can be modified to accommodate perceived, or subjective, risks ($\text{Savage 1954}$), $s$, leading to the subjective EU, or SEU model (see Shaw and Woodward 2008, for discussion):

\begin{equation}
\text{SEU} = s(\text{PPB, Sm, } z) \times U_1(x_1)
\end{equation}

\begin{equation}
+ [1 - s(\text{PPB, Sm, } z)] \times U_2(x_2)
\end{equation}

Equation (3) yields the subjective expected utility of a risky choice, action, or event given a person’s perceived risk. Our water-treatment decision is discrete. If the subject chooses not to treat, they enjoy income $Y$ but endure exposed risk from arsenic consumption ($R_a$). Define the subjective expected utility from the decision to not treat as $\text{SEU}_{\text{NT}}$. In contrast, one can reduce the risk of lung or bladder cancer down to background levels, $R_b$, by treating water effectively, but by doing so, income will be reduced by the cost of treatment ($C_T$). Define the subjective expected utility given treatment of drinking water as $\text{SEU}_T$. Formally, the underlying model is such that we assume the individual compares subjective expected utility with treatment and background risk, $R_b$, but with treatment costs, to the subjective expected utility without treatment, facing risks, $R_a$, but no treatment costs. A household pursues and adopts water treatment when $\text{SEU}_T$ exceeds $\text{SEU}_{\text{NT}}$, or

\begin{equation}
\text{SEU}_T[R_b(\text{PPB}), Y - C_T, \text{Sm, } z] + \varepsilon_T
\end{equation}

\begin{equation}
> \text{SEU}_{\text{NT}}[R_a(\text{PPB}), Y, \text{Sm, } z] + \varepsilon_{\text{NT}}
\end{equation}

where $\varepsilon_j$ for $j = T, \text{NT}$ represents measurement error on the part of the researcher concerning the true subjective expected utility. It is this relationship that is the basis of our empirical discrete choice model of whether a person decides to treat drinking water to remove arsenic. Other frameworks are certainly possible (Konishi and Adachi 2010), leading to different empirical models.

IV. THE DATA

The sampling strategy, survey implementation, and other aspects of data collection are described in greater detail elsewhere (Nguyen et al. 2010). Briefly, a random sample of subjects was contacted in arsenic hotspots of the United States, including Albuquerque, New Mexico; Fernley, Nevada; Oklahoma City, Oklahoma; and Appleton, Wisconsin. The level of arsenic in a household’s tap water depends on the location and what kind of water system serves the household (public vs. private), but most households in the sample have arsenic in their water supplies two to four times the new 10 ppb arsenic standard. All households on public systems were in compliance with the old standard of 50 ppb, but some households served by unregulated private wells had arsenic concentrations in excess of 50 ppb.

We communicate arsenic exposures and scientists’ best estimates of the risk of lung and bladder cancer using a telephone–mail–telephone survey format. Subjects were initially contacted through random-digit dialing, asked a series of screener questions, and then asked if they would be willing to receive an information booklet and participate in follow-up survey. If the respondent to the screener survey agreed to further participation, a future telephone interview was scheduled and they were mailed an information booklet containing information on arsenic risks and the new federal standard. Households were ineligible to participate if the respondent was a renter and did not pay the water bill, or if the respondent was under the age of 18.

Of the 733 individuals who completed the screener survey (~31% of those initially contacted), some 565 agreed to participate in the follow-up survey. However, when attempts were made to follow-up with the 565 willing participants, some could not be contacted, changed their minds, or otherwise chose not to participate in the second round, leaving 353

4. Before 2001, the EPA standard for arsenic in drinking water was 50 ppb. The new standard is 10 ppb.

5. The screener allows us to exclude those who do not pay for their water. The screener also included demographic questions and questions about the subject’s preferences over general environmental quality.
respondents who completed all phases of the survey.\textsuperscript{6}

The information brochure reported the arsenic concentration reported by their local water provider, the long-term mortality risks from drinking water with arsenic at a concentration of 50 ppb, and additional factors that may mitigate or inflate these risks.\textsuperscript{7} Subjects were informed that ingesting arsenic has a cumulative effect resulting in higher risks: health effects are not immediate, but may take 15–20 years to occur.\textsuperscript{8} Risks are depicted using a common risk communication and elicitation device, the risk ladder. The ladder is presented in Jakus et al. (2009), and depicts the mortality rates for eight events, ranging from the relatively common (heart disease) to the relatively uncommon (lightning-strike). The ladder also included baseline mortality rates for lung and bladder cancer, as well as best scientific estimates for lung and bladder cancer due to arsenic exposure at 50 ppb over 15–20 years, for both non-smokers and smokers. While the risk ladder, like all other risk communication devices, may influence risk perceptions (Weinstein 1999), respondents in the three focus groups used to develop survey materials indicated it would be the easiest and most straightforward means of communicating and eliciting risks, especially for small probabilities (those below 0.01). The ladder has the additional advantage of enabling uncertain subjects to readily provide lower and upper bounds for their perceived risk by referencing the rungs of the ladder (Riddel and Shaw 2006; Viscusi and Zeckhauser 2006).

Subjects received the information brochure in the mail at least a week prior to the follow-up interview. The brochure asked respondents to examine the information and risk ladder, and to think about their risk of exposure to arsenic. They were also asked to mark a single point estimate of risk on the risk ladder, or a range from low to high, whichever they felt more comfortable doing, for their personal mortality risk related to arsenic and smoking (see Appendix 2 for the exact question). Respondents were also asked to have the information booklet in hand during the interview. During the second phone call, the interviewer asked the respondent where he or she had made their mark (or marks) on the ladder.

The final dataset provides responses on perceived risks of arsenic, past and present smoking behavior, water-treatment behavior, and demographic variables that may explain risk-related perceptions and behaviors. The survey was not designed to explore smoking behavior in depth, hence we do not have the data needed to predict the probability a person smokes or smoked at some time in the past. Table 1 compares key variables for the original 733 observations from the screener survey, and the 353 who completed all survey activities. We formally examine potential sample-selection effects in statistical modeling presented later in the paper.

\begin{table}[h]
\centering
\caption{Mean or Frequency Comparison: Original \textit{(n = 733)} and Final Sample \textit{(n = 353)}}
\begin{tabular}{llll}
\hline
Variable & Screener Sample & Final Responding Sample \\
\hline
Age (years) & 51 & 51 \\
Males (%) & 53.3 & 57.7 \\
Years in current residence & 11.9 & 11.3 \\
On public water system & 74.9 & 68.6 \\
Importance of environmental quality (Low = 1, High = 5) & 2.6 & 2.9 \\
& 3.1 & 3.2 \\
& 4.2 & 4.5 \\
& 5.95 & 6.18 \\
Annual household income & $69,997 & $69,190 \\
Education (years) & 8.4 & 8.4 \\
& 10.2 & 10.3 \\
& 12.2 & 12.4 \\
& 13.2 & 13.8 \\
& 14.7 & 14.7 \\
& 16.1 & 16.4 \\
& 18.1 & 18.4 \\
Former smoker (%) & 33.2 & 33.2 \\
Current smoker (%) & 12.4 & 12.4 \\
Never smoker & 54.4 & 54.4 \\
Intended to participate in second round & 71.1 & 71.1 \\
Actually participated in second round & 48.2 & 48.2 \\
\hline
\end{tabular}
\end{table}
V. PERCEIVED ARSENIC RISKS FOR CURRENT, PAST SMOKERS, AND NON-SMOKERS

Some 56 respondents could not provide either a point or a range estimate, leaving a useful sample of 297 responses. Of this number, 141 respondents (47.5%) indicated that they currently smoked or had smoked sometime in the past, whereas 156 said they had never smoked. Of the 141 subjects who had ever smoked, 40 (28.4%) are current smokers and the remaining 116 (71.6%) reported that they had quit at the time of the survey. Thus, roughly 13.5% of the 297 usable responses are current smokers. We distinguish between current and former smokers because many studies suggest that ex-smokers might be different from current smokers or non-smokers in terms of their risk preferences (Smith, Taylor, and Sloan 2001; Viscusi 2002). Ex-smokers may perceive higher smoking risks and/or have lower rates of time preference than current smokers.

In addition to perceived risk, current smokers, ex-smokers, and non-smokers may differ in regard to demographic characteristics. Statistical differences were found between those who had ever smoked (current and ex) and those who had never smoked for only gender and income. Smokers were more likely to be male than non-smokers (62% vs. 53%, \( p = .06 \)); smokers’ household incomes were less than non-smokers’ (\sim $60,000 vs. $74,000, \( p = .01 \)). Other demographic variables for which we have data (age, years of education, home ownership, and race) showed no significant differences across smokers and non-smokers.

Table 2 reports mean perceived arsenic-related mortality risks for our sample. The top half of Table 2 shows mean perceived risks for the 201 respondents who provided point estimates of the risk, whereas the bottom half of the table shows the midpoint of the range of perceived risks as reported by the 96 respondents who did not provide a point estimate. The most striking aspect of the data is that the relative risks between non-smokers, former smokers, and current smokers follow a pattern that is reasonably comparable to the science-based risks. Smokers (current and ex) report roughly double the average risk of non-smokers, so that the relative perceived risk is consistent with the current scientific thinking that they are informed of in the brochure. Among those providing point estimates of risk, former smokers report arsenic health risks that are approximately half that of current smokers. This is consistent with studies that indicate that smokers who quit around age 50 reduce their risk of dying prematurely by 50% compared to those who continue to smoke (Doll et al. 2004). Non-smokers provided the lowest perceived risk estimates of all: just less than one-fourth of the risk reported by smokers and two-thirds the risk reported by former smokers.

The bottom half of Table 2 reports risk estimates for the 96 people who were more comfortable providing a range than a point estimate, again broken down into non-smokers, former smokers, and current smokers. These results show a slightly different pattern than those providing a point estimate. Although the relative risks of non-smokers, ex-smokers, and smokers remains the same, the differences between the groups is much narrower relative to the group reporting point estimates. Smokers’ perceived risks are only 40% greater than non-smokers, relative to more than triple the risk for those reporting point estimates. The mean perceived risk for current smokers is only 10% greater than that of former smokers (for point estimate respondents perceived risks of current smokers were more than double those of former smokers).

The propensity for some subjects to report a range suggests a degree of uncertainty about subjective risk even after they have seen the information brochure and the risk ladder.

### Table 2

Mean Perceived Arsenic-Related Mortality Risks for Smokers and Non-smokers

<table>
<thead>
<tr>
<th>Groupa</th>
<th>Mean (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point estimates</strong></td>
<td></td>
</tr>
<tr>
<td>Full sample who report point estimates (( n = 201 ))</td>
<td>0.0059 (0.0007)</td>
</tr>
<tr>
<td>Never smoked (( n = 102 ))</td>
<td>0.0038 (0.0007)</td>
</tr>
<tr>
<td>Smokers (( n = 99 ))</td>
<td>0.0081 (0.0013)</td>
</tr>
<tr>
<td>Ex-smokers (( n = 71 ))</td>
<td>0.0058 (0.0014)</td>
</tr>
<tr>
<td>Current smokers (( n = 28 ))</td>
<td>0.0139 (0.0028)</td>
</tr>
<tr>
<td><strong>Range estimates</strong></td>
<td></td>
</tr>
<tr>
<td>Full sample who report range estimates (( n = 96 ))</td>
<td>0.0043 (0.0006)</td>
</tr>
<tr>
<td>Never smoked (( n = 54 ))</td>
<td>0.0032 (0.0006)</td>
</tr>
<tr>
<td>Smokers (( n = 42 ))</td>
<td>0.0051 (0.0010)</td>
</tr>
<tr>
<td>Ex-smokers (( n = 30 ))</td>
<td>0.0050 (0.0013)</td>
</tr>
<tr>
<td>Current smokers (( n = 12 ))</td>
<td>0.0055 (0.0018)</td>
</tr>
</tbody>
</table>

aThe top half of the table includes only those who reported a point estimate for subjective risks whereas the bottom half includes the group who reported a range rather than point estimate. The mean risk for this second group is calculated using the average of the individual’s high and low estimate.
TABLE 3
Perceived Risk Models

<table>
<thead>
<tr>
<th>Variable</th>
<th>OLS Model for Point Estimate Subjects (N = 192)</th>
<th>Interval Model for Range Subjects (N = 96)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>Coefficient = -0.022 (p value = .04)</td>
<td>Coefficient = -4.59 x 10^-5 (p value = .99)</td>
</tr>
<tr>
<td>Arsenic concentration</td>
<td>1.68 x 10^-4</td>
<td>-5.86 x 10^-6</td>
</tr>
<tr>
<td>Never smoker</td>
<td>-0.002</td>
<td>1.24 x 10^-4</td>
</tr>
<tr>
<td>Current smoker</td>
<td>0.007</td>
<td>0.002</td>
</tr>
<tr>
<td>Health status (1 = excellent, 5 = poor)</td>
<td>0.003</td>
<td>-1.10 x 10^-4</td>
</tr>
<tr>
<td>Public water system</td>
<td>0.015</td>
<td>0.001</td>
</tr>
<tr>
<td>Years in current residence</td>
<td>-7.12 x 10^-5</td>
<td>1.05 x 10^-4</td>
</tr>
<tr>
<td>Male</td>
<td>-0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Education</td>
<td>1.25 x 10^-4</td>
<td>3.34 x 10^-5</td>
</tr>
<tr>
<td>Adjusted R^2</td>
<td>0.212</td>
<td>20.92</td>
</tr>
</tbody>
</table>

^p values are for a two-tail test that the coefficient is equal to zero.

is not surprising since the information brochure highlighted the fact that scientists’ estimates of arsenic risk are not precise. One way to think about subjective uncertainty is that the respondent has some underlying (subjective) risk distribution. When queried about risks, they report a range associated with this distribution. If the subjective risk distribution is symmetric, then the midpoint of the range is an unbiased estimate of the mean; however, if the underlying distribution is skewed in one direction or another, then the midpoint of the range either under- or over-estimates the mean risk. In this paper, we assume a symmetric risk distribution and recognize that there may be some measurement error in the estimated average perceived risk for uncertain subjects if this assumption is violated.

A. Perceived Risk Models
Table 3 presents models of respondents’ stated perceived risk. For those who provide a point estimate, a simple regression is used (left-hand column), similar to Jakus et al. (2009). In recognition that those who provide a range might be quite different than those who provide a point estimate, a separate interval regression model is used (the right-hand column). Each model allows prediction of the subjective risk, and below we only discuss coefficients that are significantly different from zero at conventional levels (p < .10). We present relatively parsimonious specifications; other specifications (not reported) show that income and other demographic variables do not significantly influence the mean perceived risk. In fact, including them causes other variables to become insignificant. We infer that multicollinearity is an issue and report the best models as evaluated by the number of significant variables and goodness of fit.

Turning first to perceived risks of those who provided a point estimate, column 2 of Table 3 shows that as the arsenic concentration in a community increases, perceived risk increases. Smokers report greater perceived risks than those who have never smoked and those who have quit (our baseline respondent). The better the self-reported health status of the subject, the lower the respondent’s perceived risk. Finally, perceived risk is related to whether or not one is on a publicly supplied water system: those who are on public systems report perceived risks that are greater than those who have private wells. The interval model (column 3) yields rather different results, which is likely due to this group feeling more uncertain about risks of exposure to arsenic. The coefficient of arsenic concentration (PPB) has an unexpected negative sign, but the

9. We also estimated a model transforming the dependent variable to a log odds, but the results were little different than the OLS model.

10. PPB levels specific to each household are not available, so we use the concentration as reported by the local water authority or, in the case of private wells, the concentration known to occur in the region. We also estimated models with regional fixed effects, but the regional indicators were not statistically significant.

11. A reviewer of this paper speculates that this may be due to the fact that these systems are required to send annual water quality reports to its customers.
standard error of the coefficient is high and
the variable is not statistically significant. Being
a current smoker has a positive influence on
perceived risk, but this is not quite significant
at conventional levels (p value is .11). The
number of years a person has lived in their
residence has a positive influence on stated
risks. Unlike respondents who provided point
estimates of risk, gender plays a significant role
in that males believe risks to be higher than
females.

Recall that scientists’ estimate of the mortal-
ity risk from arsenic exposure for non-smokers
is roughly 0.01 (1,000 deaths out of 100,000
people) when exposed to 50 ppb of arsenic for
15 to 20 years, whereas the risk for smokers is
thought to be approximately double that (0.02,
or 2,000 deaths). Evaluated at mean values of
the explanatory variables, the estimated per-
ceived mortality risk of non-smokers exposed to
50 ppb who provided point estimates is approxi-
ately 0.004, or 400 deaths out of 100,000 peo-
ples. For smokers, the perceived risk at 50 ppb is
0.0127, or 1,270 deaths per 100,000. Both esti-
mates are about half of what scientists believe
the risk to be. A similar story holds for those
providing a risk range. When exposed to con-
centrations of 50 ppb, non-smokers who pro-
vided a range estimated their risk at 0.003,
or 300 deaths for every 100,000 people. For
smokers, this estimate rises to 0.005 (500
deaths per 100,000). It is clear that subjective
risks lie considerably below those estimated by
scientists.

Whereas the model suggests that subjects
underestimate the risks from arsenic contami-
nation, the relative risks for smokers and non-
smokers are fairly accurate. Recall that the
scientific consensus is that smoking doubles
the health risks from arsenic. According to
the model, smokers who offered a point esti-
mate perceive risks to be about three times
that of non-smokers and former smokers. For
uncertain subjects, smokers perceive risks that
are roughly 1.7 times higher than non-smokers
and former smokers. We offered similar find-
ings in Table 2 when we compared the simple
mean perceived risks across the smoking sta-
tus categories. Taken together, the model results
and simple mean comparisons imply that sub-
jects perceive their subjective risks to be lower
than the experts’ assessments of those risks,
but they have a reasonably accurate view of
the compounding effects of smoking on health
risks.

<table>
<thead>
<tr>
<th>TABLE 4</th>
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<tbody>
<tr>
<td>Frequencies of Water-Treatment Decisions</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Group (n)</td>
</tr>
<tr>
<td>Full sample (353)</td>
</tr>
<tr>
<td>Never smoked (192)</td>
</tr>
<tr>
<td>Smokers (161)</td>
</tr>
<tr>
<td>Ex-smoker (116)</td>
</tr>
<tr>
<td>Current smoker (45)</td>
</tr>
</tbody>
</table>

Notes: Respondents reporting some type of in-home water-treatment device. n is number of observations for sample or sub-sample. Within any column, none of the percentages is significantly different from any other at the 5% levels using a two-sided test. Using a one-side test, the proportion of current smokers who treat drinking water is significantly less than that of ex-smokers who treat (p = .07).

VI. WATER TREATMENT DECISIONS FOR SMOKERS AND NON-SMOKERS

Given these perceived risks, we now address
water-treatment behavior that may reduce these
risks. In particular, we explore differences in averting behavior between smokers and non-
smokers to test whether or not smokers’ higher
risk perceptions lead to an increase in the like-
lihood of averting behavior. Using an effective
water-treatment device, such as reverse osmosis,
can eliminate arsenic and therefore the risk of
dying from cancers related to ingesting arsenic.
If risk perceptions are consistent with averting
behavior, we would expect that those with
higher perceived risk to be more likely to treat
their water, holding other factors constant. As
Table 4 shows, 52% of our 353 respondents
treat their water with some type of device.

Although it would appear that the proportion
of current smokers who treat drinking water is
smaller than the other respondent types, two-
sided tests showed no significant differences
between groups. However, as noted at the bot-
tom of Table 4, there is some evidence (p = .07)
that current smokers treat less, as a propor-
tion, than do ex-smokers.

There are many reasons why a household
might choose to treat their water, and a sim-
ple comparison of sample proportions does not

12. Our survey asked about the type of drinking water
treatment device used in the household, including osmosis,
distillation, ionizers, charcoal, and “other.” Some 54 respon-
dents reported having a reverse osmosis system, but 91 said
that they had some “other” kind of device; we do not know
what that device may be. Several respondents reported hav-
ing multiple devices. We assume that treatment is perceived
to be an action that reduces risks.
control for these other factors. To pursue the

treatment decision further, we first estimate a

simple probit model of the decision to treat

water, controlling for perceived risk, income,

water consumption decisions, tenure at current

residence, the type of water system (public

or private), and smoking status. The treatment

models assume that smoking status is an exoge-

nous factor. This assumption has been shown to

be problematic in models of smoking mortality

risk (Lundborg 2007) but we do not attempt to

explain smoking behavior in this study. Rather,

our goal is to explain behavior that may miti-

gate the risks associated with arsenic exposure.

Our explanation of arsenic risks (i.e., the risk

ladder and text in the brochure) treated smok-

ing status as exogenous. Still, the possibility

of endogenous response cannot be eliminated

because, as previously noted, we do not have the
data needed to fully explore variation in smok-
ing behavior in a separate model.13

Table 5 reports the estimates of two probit

models that explain the discrete water-treatment
decision.14 The reported model controls for the

predicted perceived risk (based on the models in

Table 3), smoking status, tenure at the respon-
dent’s current residence, the degree to which the

respondent relies upon tap water, and whether

household tap water is supplied by a public

water system or a private well. The two

specifications in Table 5 differ in their con-

trol for household income; Specification 1 does

not control for income whereas Specification 2

does. The models are robust to the treatment

of income, so our discussion applies to both

specifications.

The perceived risk of exposure to arsenic
does not appear to influence the treatment deci-
sion. The fact that risk is insignificant is some-
what disconcerting, however, there are many

reasons why people might treat their tap water,

and arsenic contamination is only one of them.

Many people treat drinking water simply to

improve the taste, eliminate odor, or treat for

other contaminants. Indeed, smoking may affect
the taste of water. Apparently, enough of the

subjects in our sample treated for non-risk-

related reasons that it is not possible to identify
a subgroup who treated primarily to reduce the

arsenic contamination risk.

Perhaps of greatest interest are differences

in water-treatment decisions by smoking sta-

tus. Naturally, we are just looking for asso-

ciation here, as smokers who only learned

that they were at higher risks upon receiving

treatment costs (linear and nonlinear) and interactions with
treatment cost. Treatment costs were never statistically

significant. The results reported in Table 5 are robust to

these many specifications.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Specification 1</th>
<th></th>
<th>Specification 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>(p value)</td>
<td>Coefficient</td>
<td>(p value)</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.486</td>
<td>(.052)</td>
<td>–0.767</td>
<td>(.640)</td>
</tr>
<tr>
<td>Predicted perceived risk</td>
<td>19.374</td>
<td>(.393)</td>
<td>28.498</td>
<td>(.229)</td>
</tr>
<tr>
<td>Never smoker</td>
<td>–0.390</td>
<td>(.026)</td>
<td>–0.364</td>
<td>(.044)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>–0.643</td>
<td>(.023)</td>
<td>–0.662</td>
<td>(.020)</td>
</tr>
<tr>
<td>All water from tap</td>
<td>0.547</td>
<td>(.001)</td>
<td>0.570</td>
<td>(.001)</td>
</tr>
<tr>
<td>Years in current residence</td>
<td>–0.024</td>
<td>(.000)</td>
<td>–0.021</td>
<td>(.003)</td>
</tr>
<tr>
<td>Public water system</td>
<td>–0.588</td>
<td>(.002)</td>
<td>–0.632</td>
<td>(.001)</td>
</tr>
<tr>
<td>Ln (Net income)</td>
<td>–</td>
<td></td>
<td>0.109</td>
<td>(.449)</td>
</tr>
<tr>
<td>Chi-square (β = 0)</td>
<td>34.10</td>
<td>(.000)</td>
<td>33.91</td>
<td>(.000)</td>
</tr>
<tr>
<td>Pseudo R²</td>
<td>0.085</td>
<td></td>
<td>0.089</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>288</td>
<td></td>
<td>270</td>
<td></td>
</tr>
</tbody>
</table>

Note: Dependent variable 1 = Treat, 0 = Do not treat. Predicted Perceived Risk calculated from models appearing in Table 4.

*p values are for a two-tail test that the coefficient is equal to zero.
the information brochure are unlikely to have rushed out to purchase a water-treatment system. Current smokers appear less likely to treat their water than either ex-smokers (the baseline group) or those who never smoked. Those who have never smoked are less likely to treat than ex-smokers, and ex-smokers are the most likely to treat. Our interpretation is that current smokers are less likely to protect themselves than non-smokers (both those who have quit and those who never smoked) against risks other than smoking.\footnote{15}

The reason for the apparent difference between current smokers and others is unclear, but rational addiction models suggest that either time-discounting or heterogeneity in risk preferences may be at work (Becker and Murphy 1988; Kenkel 2000). If smokers and those who never smoke employ different discount rates for health, then those with the higher discount rate would be more likely to smoke and less likely to engage in averting behaviors. Alternatively, smokers and never smokers may have different levels of health-risk aversion. Simply put, current smokers may be reasonably aware of the risks, but are relatively less risk averse than ex-smokers or non-smokers and therefore less likely to engage in averting behaviors in general. Another possibility is that ex-smokers are people who, at one time, carefully thought about the risks associated with smoking (and perhaps associated risks, such as arsenic), while other respondents have not done so.\footnote{16} More data would be necessary to distinguish between these two explanations of risk divergence, as well as scrutiny of the overall distribution, rather than just the mean.\footnote{We estimated two models to test for sample-selection effects. The selection procedure we use corrects for bias that could occur if those individuals who treat their water are more or less likely to complete the final survey than the group that only completed the screener, but then terminated their involvement.\footnote{An auxiliary income regression was used to predict income for those respondents not reporting income.} We examine two potential sources of bias: (1) bias between the sample that completed the initial screener ($n = 733$) and the final sample ($n = 353$) and (2) bias between the sample that intended to participate in the follow-up survey ($n = 565$) and the final sample ($n = 353$). The selection equation includes variables thought to influence participation in the survey. Potential participants were told that the second survey would concern arsenic and drinking water. Prior to informing respondents of the follow-up survey, they were asked about the level of importance attributed to environmental quality relative to other public goods such as affordable health care and good schools for children. The importance scale was 1 to 5, with 5 being very important. Other variables that might influence whether or not the subject either actually or intended to participate are the subject’s age, gender, income, and their years at their current residence.

In the top portion of Table 6, the water-treatment model is reported, with the bottom half including the specifications for the actual and intended participation equations. The two selection equations are statistically very similar. The more important environmental issues were believed to be, the more likely the respondent completed the second survey and was included in the treatment model. The longer the respondent lived at their current residence the less likely they were to participate, although the relationship is only statistically significant in the participation model of column 2. Males were more likely to participate and complete the follow-up survey. Age and income did not affect participation in the follow-up survey. Of most interest here is the statistical significance of $\rho$, which represents the correlation between the participation and treatment selection processes.}

With regard to other factors that may influence the treatment decision, those who report using only tap water for drinking are less likely to treat than those who use other water sources than the tap. The longer the respondent has reported living in their residence, the less likely they will treat their water, holding other things constant. Further, those who receive water from public water systems are less likely to treat than those on wells. In Specification 2, the log of net income (income less treatment costs) is insignificant; we reject the hypothesis of income effects in the treatment decision.\footnote{We make no claim in this paper that the sample is representative of the general population in the United States; our survey effort took place only in arsenic hot spots.}

A. Sample-Selection Effects on Water Treatment

We estimated two models to test for sample-selection effects. The selection procedure we use corrects for bias that could occur if those individuals who treat their water are more or less likely to complete the final survey than the group that only completed the screener, but then terminated their involvement.\footnote{An auxiliary income regression was used to predict income for those respondents not reporting income.} We examine two potential sources of bias: (1) bias between the sample that completed the initial screener ($n = 733$) and the final sample ($n = 353$) and (2) bias between the sample that intended to participate in the follow-up survey ($n = 565$) and the final sample ($n = 353$). The selection equation includes variables thought to influence participation in the survey. Potential participants were told that the second survey would concern arsenic and drinking water. Prior to informing respondents of the follow-up survey, they were asked about the level of importance attributed to environmental quality relative to other public goods such as affordable health care and good schools for children. The importance scale was 1 to 5, with 5 being very important. Other variables that might influence whether or not the subject either actually or intended to participate are the subject’s age, gender, income, and their years at their current residence.

In the top portion of Table 6, the water-treatment model is reported, with the bottom half including the specifications for the actual and intended participation equations. The two selection equations are statistically very similar. The more important environmental issues were believed to be, the more likely the respondent completed the second survey and was included in the treatment model. The longer the respondent lived at their current residence the less likely they were to participate, although the relationship is only statistically significant in the participation model of column 2. Males were more likely to participate and complete the follow-up survey. Age and income did not affect participation in the follow-up survey. Of most interest here is the statistical significance of $\rho$, which represents the correlation between the participation and treatment selection processes.
TABLE 6

Water Treatment Decision with Selection Correction for Participation

<table>
<thead>
<tr>
<th>Model/Variable</th>
<th>Actual Participation (353/733)</th>
<th>Coefficient</th>
<th>(p value)</th>
<th>Intended Participation (353/565)</th>
<th>Coefficient</th>
<th>(p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>$-0.927$ (480)</td>
<td></td>
<td></td>
<td>$-1.449$ (233)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted perceived risk</td>
<td>$-5.2 \times 10^{-5}$ (774)</td>
<td></td>
<td></td>
<td>$-6.1 \times 10^{-5}$ (722)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoker</td>
<td>$-0.207$ (175)</td>
<td></td>
<td></td>
<td>$-0.167$ (223)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current smoker</td>
<td>$-0.450$ (054)</td>
<td></td>
<td></td>
<td>$-0.380$ (091)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All water from tap</td>
<td>$0.545$ (.001)</td>
<td></td>
<td></td>
<td>$0.507$ (.004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years in current residence</td>
<td>$-0.021$ (.001)</td>
<td></td>
<td></td>
<td>$-0.018$ (.004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ln (Net income)</td>
<td>$-0.623$ (003)</td>
<td></td>
<td></td>
<td>$-0.719$ (.056)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participation Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>$-0.122$ (762)</td>
<td></td>
<td></td>
<td>$-0.521$ (099)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Importance of environmental quality</td>
<td>$0.183$ (.007)</td>
<td></td>
<td></td>
<td>$0.104$ (.045)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>$-0.001$ (794)</td>
<td></td>
<td></td>
<td>$-0.001$ (.733)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>$0.251$ (043)</td>
<td></td>
<td></td>
<td>$0.219$ (.021)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income</td>
<td>$1.63 \times 10^{-3}$ (333)</td>
<td></td>
<td></td>
<td>$1.58 \times 10^{-3}$ (284)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years at current residence</td>
<td>$-0.012$ (.019)</td>
<td></td>
<td></td>
<td>$0.006$ (.141)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P$</td>
<td>$0.625$</td>
<td></td>
<td></td>
<td>$0.625$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood ratio test ($p = 0$)</td>
<td>$1.32; \text{Prob} &gt; \chi^2 = 0.254$</td>
<td></td>
<td></td>
<td>$1.27; \text{Prob} &gt; \chi^2 = 0.260$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $p$ values are for a two-tail test that the coefficient is equal to zero. Variables are defined in Tables 1–3.

equations. In both models, $\rho$ is not statistically different from 0, indicating that selection effects do not compromise the treatment equation. Indeed, this finding is underscored by a comparison of the treatment models with and without selection. By and large, the variables explaining the decision treatment have the same magnitude and level of statistical significance. The one meaningful difference is that Never Smoker is statistically significant in the standard treatment model (Table 5), but not in the treatment model with selection (Table 6). We conclude that selection effects have not induced undue bias in the treatment models.

VII. CONCLUSIONS

Arsenic contamination remains a problem not only in within the United States but also in other countries (Carson, Koundouri, and Nauges 2010). Most studies of risk perceptions for smokers have strictly examined smoking-related risks, but here we examine an environmental risk that can be exacerbated by smoking behavior. We consider smokers’ perceptions of and averting behavior in response to the conditional mortality risk of smoking and arsenic exposure, and compare smoker’s response to those of non-smokers.

We find evidence that smokers and non-smokers alike tend to underestimate the risk from ingesting arsenic in their drinking water. In contrast, relative perceived risks across smokers and non-smokers correspond well to the relative science-based risks presented to respondents. Even though all respondents in our sample receive information (as opposed to a split-sample design, where some respondents do not receive information), this result cannot be taken for granted. Many studies provide information to respondents, but the respondents fail to comprehend the science-based risks, or continue to report wildly different subjective estimates. In our sample, smokers’ perceived risks are two to three times greater than the perceived risks of non-smokers, which is consistent with the best science-based estimates (although these perceived risks fall short of what scientists believe the risk to be). Smokers thus appear to use the information given to them in the brochure and process their own subjective risks in a manner consistent with that information. The ability to adequately process the information presented to them regarding smoking risks suggests that smokers and non-smokers have a good understanding of the relative risk of smoking, but perhaps make common mistakes in understanding the baseline risk from arsenic they share.
We find that current smokers are less likely to treat their water than either ex-smokers or non-smokers, a behavior seemingly at odds with their higher subjective assessment of the risk. This result persists when we control for other factors that may influence averting behavior as well as treatment effects. We infer that this somewhat unexpected result may arise from either heterogeneity in time preferences between smokers and others, or perhaps differences in their risk preferences, surmising that smokers have a higher rate of time preference with respect to health issues and/or display less risk aversion than do non-smokers and ex-smokers.

APPENDIX 1: RISK INFORMATION CONVEYED BY BROCHURE

Can drinking water with arsenic increase my risk of getting cancer?

- No arsenic in drinking water, baseline risk. The risk of dying from lung or bladder cancer in your lifetime, whether or not you smoke, is such that 60 of every 100,000 people will die in the normal course of life. This is called the “baseline risk.” Please note this point, which is in the middle of the “risk ladder” diagram on the following page.
- No arsenic in drinking water, smoke or exposed to high levels of second-hand smoke. The risk of dying from lung or bladder cancer in your lifetime if you smoke or if you are exposed to high levels of second-hand smoke is much higher than this, ranging from 1 in 100 (or 1,000 out of every 100,000 people) to 16 in 100 (or 1,600 out of every 100,000 people). This rate varies depending on your age and the amount you smoke. On the risk ladder, this is near the top, but we don’t show it there specifically. Even at the low end, this would be over 15 times higher than the baseline risk.
- Drinking water with 50 ppb of arsenic steadily for 15 to 20 years results in a 2 in 100 (2,000 in 100,000 on the risk ladder) chance of getting lung or bladder cancer in your lifetime if you smoke or if you are exposed to high levels of second-hand smoke.
- Scientists today believe that the new standard of only 10 ppb in your water is at a level that is safe to drink. However, the precise level of risk between 10 and 50 ppb is not well known. Research is on-going.
- Your risks will be lower if you drink less tap water every day than the “average” person does.
- If you use a filter or water system that removes arsenic then your risk of lung or bladder cancer drops to the baseline risk.
- Your risk could also vary depending on other factors, such as your current health and age.

APPENDIX 2: RISK ELICITATION QUESTIONS

Text from information brochure

Think about your risk of dying from lung or bladder cancer from drinking water with arsenic in it at the current levels you have for twenty years. Please look at the risk ladder on the next page and determine where on that ladder you think your certainty of risk would fall.

- If you are certain about your risks of dying, please put a single mark on the Risk Ladder 1 (on the next page) indicating your own risk of dying. When we call you for your scheduled telephone interview, we will ask you about this mark.

Interviewer’s text from follow-up telephone call

Now we want to find out your thoughts about risks. Please look at pages 8 and 9 of the information brochure we mailed you.

1. I want to ask you about the risks that you think you face. Look at Page 9 of the brochure, Risk Ladder 1. Did you make one mark or two marks?

2. One mark → What line did you make your mark on?

3. Two marks → What was the highest line you made your mark on?

4. Did not mark any yet

5. Cannot decide where to mark

6. Refused to make marks → Why do you refuse to make the marks?

REFERENCES


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