

Parental decisions, child health and valuation of avoiding arsenic in drinking water in rural Bangladesh

Sonia N. Aziz, Kevin J. Boyle and Tom Crocker

ABSTRACT

Arsenic contamination of groundwater in Bangladesh is a widespread public health hazard. Water sources without high arsenic levels are scarce, affecting people's availability for work and other activities when they have to seek safe water to drink. While children are particularly susceptible to chronic arsenic exposure, limited information and heavy constraints on resources may preclude people in developing countries from taking protective actions. Since parents are primary decision-makers for children, a model of stochastic decision-making analytically linking parent health and child health is used to frame the valuation of avoiding arsenic exposure using an averting behavior model. The results show that safe drinking water programs do work and that people do take protective actions. The results can help guide public health mitigation policies, and examine whether factors such as child health and time required for remediation have an effect on mitigation measures.

Key words | arsenic in drinking water, averting behavior, health production, parental valuation of child health, willingness to pay for health risk reduction

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INTRODUCTION

Rural households in developing countries face many competing sustenance-based needs. In this context, taking protective actions in response to public health crises may be trumped by other basic needs for survival. However, the health of a child in the household may dictate a higher demand for good health outcomes. In this paper we investigate how parents in a developing country react to public health warnings, and use this to frame parent's valuation of their own and their child's health in the context of arsenic in drinking water in rural Bangladesh.

According to the World Health Organization (WHO), 'arsenic contamination of ground water has been found in many ... countries, including Argentina, Chile, China, India, Mexico, Taiwan, Thailand and the United States ... But Bangladesh's plight is unprecedented ... At least 100,000 cases of debilitating skin lesions are believed to have already occurred' (WHO 2001). Health effects from arsenic exposure range from chronic to acute, where chronic arsenic poisoning due to long-term exposure through drinking water is very different from acute

poisoning. The WHO reports 'immediate symptoms (from acute poisoning typically include vomiting, oesophageal and abdominal pain, and bloody "rice water" diarrhea' (WHO 2012). The WHO also states that 'following long-term exposure, the first changes are usually observed in the skin: pigmentation changes, and then hyperkeratosis. Cancer is a late phenomenon, and usually takes more than 10 years to develop.' Additional health effects from chronic arsenic poisoning include neurological effects, hypertension, peripheral vascular disease, cardiovascular disease, respiratory disease, diabetes mellitus and other malignancies (Yoshida *et al.* 2004). Most cases of acute arsenic poisoning occur from direct or accidental ingestion, while chronic arsenic poisoning appears to be the plight of most at-risk Bangladeshis (Rahman *et al.* 2001; Ratnaike 2003). The US Environmental Protection Agency (US EPA) has determined that the level at which no adverse health effects are expected, or the maximum contaminant level (MCL) goal for arsenic in drinking water is zero parts per billion (ppb, 10⁹), while the enforceable arsenic standard or the

MCL is set at 10 ppb (US EPA 2007). Bangladesh has yet to implement the U.S. EPA and WHO recommended arsenic standard of 10 ppb (0.01 mg/L concentration) for drinking water. Although there are conflicting figures, as many as 77 million people (WHO) and as few as 30 million people (Tibbets 2004) in Bangladesh are estimated to be at risk of arsenic poisoning from drinking water with arsenic levels in excess of 50 ppb or (or 0.05 mg/L) (United Nations Children's Fund (UNICEF) 2010). The public health crisis due to arsenic contamination in drinking water in Bangladesh has been described as 'the largest mass poisoning of a population in history' (Smith *et al.* 2000).

Several studies have demonstrated that households in developed countries will take actions to protect adults and their children from health risks and have estimated the implicit value parents place on reducing these child health risks (e.g. Carlin & Sandy 1991; Agee & Crocker 1996; 2007; Dockins *et al.* 2002; Dickie 2005; Dickie & Gerking 2007; Crocker *et al.* 2009; Cameron *et al.* 2010). Averting behaviors are protective actions undertaken to avoid exposure to any undesirable outcome (e.g. pollution, illness, death), and the time and expenditures associated with these actions reveal information on the implicit value placed on avoiding the undesirable outcome (Harrington & Portney 1987; Cropper & Oates 1992; Laughland *et al.* 1996). People in developing countries, however, may have limited information and heavy constraints on resources that preclude them from taking protective actions.

Groundwater is a primary source of drinking water in Bangladesh and allows households to avoid bacterial contamination of surface waters that lead to gastrointestinal diseases (Smith *et al.* 2000). Tubewells, which consist of a lined bored hole to the depth of the water table, provide the mechanism for pumping the groundwater to the surface. In rural areas of Bangladesh public health policy makers have painted tubewells green or red; green indicates that arsenic concentrations in the well water is below the Bangladesh MCL of 50 ppb and red indicates that the arsenic concentration is above this standard. The intended health message to villagers is that water from green wells is safe to drink and water from red wells is not safe to drink.

The research questions posed here ask if Bangladeshi households respond to the safe drinking-water message, green versus red wells, and if they take extra actions to

protect their children. The goal is to estimate whether averting behavior exists, and the data collected reflect observations of what people are doing to avoid the contamination. This averting-behavior investigation is developed within a household production framework of time allocation to access 'safe' water from green tubewells and the model builds on the endogenous risk framework of Ehrlich & Becker (1972) and Nastis & Crocker (2007). A unique aspect of the conceptual framework is that parent health is allowed to affect child health and vice versa. That is, an unhealthy parent may not be able to allocate as much time to protect their children's health as a healthy parent, and caring for an unhealthy child may leave parents with less time to care for their own health. The empirical investigation uses data on households' decisions to avoid arsenic exposure in the Matlab area of Bangladesh.

PREVIOUS RESEARCH

A number of papers have laid out the conceptual framework for household-production models of out-of-pocket expenditures and time allocation to avoid environmental conditions that can diminish health and otherwise reduce utility (e.g., Grossman 1972; Courant & Porter 1981; Cropper 1981; Smith & Desvouges 1986; Bartik 1988; Abdalla 1994; Whitehead *et al.* 1998; Dickie 2004; Jessoe 2013). Conceptually, averting expenditures, both out-of-pocket costs and time allocated to averting, can provide a theoretically correct measure of Marshallian surplus.

There have been many studies that have investigated averting behavior to avoid contaminated drinking water. Some examples from the literature include: Harrington & Portney (1987); Harrington *et al.* (1989); Abdalla *et al.* (1992); Collins & Steinbeck (1993); Laughland *et al.* (1993); Kocagil *et al.* (1998); Larson & Gnedenko (1999); Abrahams *et al.* (2000); Wu & Huang (2001); Um *et al.* (2002); Dasgupta (2004); Pattanayak *et al.* (2005); Shaw *et al.* (2005); Aftab *et al.* (2006); Rosado *et al.* (2006); and Roy (2008). If multiple articles were published from a single data set we only cite what appears to be the most recent article. All of these studies appear to use averting behavior that is based on households' subjective perceptions of drinking water contamination. According to Smith (1986), subjective risk, not objective risk

determines individual valuations of safety (see also Slovic *et al.* 1980). Each study typically estimates an equation for the choice of an averting method or an averting-cost equation. Only two of these studies include a health production function, *a la* Grossman (1972). Dasgupta (2004) investigated drinking water contamination in Delhi, India, using a model that included a diarrheal illness production function and an equation modeling the choice to purify drinking water. Roy (2008) estimated an averting behavior model that included a health production function where subject health is affected by arsenic in drinking water. Roy's model, based on data from West Bengal, India, included three equations where the dependent variables were sick days, medical expenses and averting expenditures. Jessoe (2013) used survey data in a household production function model from rural India, and investigated the effect of exogenous improvements in source water quality on private in-home averting expenditures. The Jessoe study did not use a health production function, and while Dasgupta and Roy used health production functions, neither study investigated whether the presence of children affected averting behavior.

Of the averting behavior studies listed above, some studies included questions on whether household averting increases when households have children. For example, Abdalla *et al.* (1992) found households are more likely to take defensive actions if they perceive increasing health risks from drinking contaminated water or have children in the household (see also Abrahams *et al.* 2000). McConnell & Rosado (2000) also found that protective actions increase with the number of small children in the household. Shaw *et al.* (2005) focused on arsenic in drinking water and presented qualitative evidence that households with children may be more likely to treat their water for arsenic than households that do not have children.

Of the empirical studies that examine parental values for their own and their child's health few analytically link the parent's value of own health to the value they attach to their child's health (Rosenzweig & Schultz 1983, 1988; Viscusi *et al.* 1987; Grossman & Joyce 1990; Carlin & Sandy 1991; Agee & Crocker 1996). Based on choices parents make to obtain health services and to reduce environmental tobacco smoke exposure for their children, Agee & Crocker (2007, 2008) estimated relative values of child health as the ratio of marginal willingness to pay for parent and child

health (parent's marginal rate of substitution between their own and their child's health). Empirical results reveal parents value their children's health nearly twice as much as their own health (Agee & Crocker 2008) and mothers who smoke value improvements in their child's health 1.5–1.7 times more than equivalent improvements in their own health (Agee & Crocker 2007).

Other studies that focus on arsenic mitigation in Bangladesh do not investigate parental values for child health. Hoque *et al.* (2004), Ahmad *et al.* (2005), Aziz *et al.* (2006), and Madajewicz *et al.* (2007) in studies of rural households from different regions in Bangladesh, found convenience to be the most compelling factor for arsenic mitigation from the households' point of view. This emphasizes the importance of incorporating the value of time in any averting behavior study that uses averting data from rural areas with time-constrained households.

This summary of the literature shows that the use of averting behavior models to model actions people take to protect their household health are well established, but the procedures for implementing these studies vary dramatically from one study to the next. Very few of these studies have been done in developing countries, have considered arsenic contamination or attempted to analytically link parent health to child health. The research presented in this paper expands this literature by investigating household arsenic avoidance decisions in a household production framework that includes health production functions for both parent and child health using data from a rural area of Bangladesh. In addition, while most other studies have investigated out-of-pocket averting expenditures, this study focuses on the time households spend procuring safe drinking water. Green wells are generally free access, but household decision-makers must walk to and from these wells to procure water. Finally, this is the first study that uses a household production framework with a health production function that allows parent health status to influence child health status and vice versa.

CONCEPTUAL FRAMEWORK

The model builds upon the endogenous risk framework of Ehrlich & Becker (1972) and Quiggin (2002) because

households can affect their exposure to arsenic through the drinking-water choices they make. A household-production framework is used to characterize activities parents take in procuring drinking water to protect their families from arsenic exposure. A representative household decision-maker who is the primary water procurer, is assumed to allocate household resources to maximize the utility of an altruistic parent, an assumption used in most research involving the economics of the family (Becker 1981; Behrman *et al.* 1995). The water procurer is typically a parent and typically the mother in our application; we will use the terms water procurer and parent interchangeably. The unitary model is an appropriate framework for this study because parents do make choices for their children. In this context health risks to children are involuntary because arsenic risk exposure decisions are made for them by their parents. Children drink the water they are provided with, eat the food that is available in the household, and go where they are taken by their parents to garner health services. Children's choices are not modeled here because they are not relevant in this study. Parents' choices for their children, however, are relevant; particularly the choices that parents make in response to perceived ambient risk levels in terms of goods, services and time. One child is included in the model (the oldest child), which allows the analysis to consider the choices parents make in taking risks for themselves and their children (Rosenzweig & Schultz 1983; Pitt *et al.* 1990; Dickie & Gerking 2003). The oldest child's health is used as an indicator for the health of all children in the family.

The conceptual framework is based on a model developed by Natis & Crocker (2007) on parental and child risk valuation. The model presented here includes an additional structural assumption that allows parent health to affect child health and child health to affect parent health.

Theoretical model

The focus of this section is to present the theoretical model of averting actions that households take to avoid exposure to arsenic-contaminated water and to use this to frame the parent's valuation of their own and their child's health. Based on this theoretical model, an empirical framework is designed to estimate marginal willingness to pay for avoiding arsenic in their own and their children's drinking water.

The model is based on endogenous risk where the household decision-maker does not know whether they or other household members will be ill from arsenic exposure. Risk is endogenous because the household takes averting actions that reduce the risk of arsenic exposure. Households choose between procuring water from a green or red well to protect themselves and their children from the health hazards posed by arsenic in their drinking water. There is a menu of technologies a household could use to mitigate exposure to arsenic in drinking water, such as pond sand filters, rain water harvesters, etc., but our data indicate that these other technologies are rarely used. Thus, for our model we have a binary choice between using green and red wells, but the theoretical framework could accommodate multiple technologies. Arsenic poses only a health hazard; it does not affect the taste or smell of water. Thus, the choice between green and red wells does not affect the palatability of the water. Protection technologies can alter the probability of an arsenic-related health effect being realized as well as the severity of any realized effect. Each technology has three basic aspects: access, effectiveness and intensity of use.

Access is a binary variable with two states: failure or success. Access failure here occurs because a household does not use a green well for drinking water. Effectiveness depends on the intensity of use of green wells.

Household members do not know whether they will become ill from drinking water from a red well. Thus, the theoretical specification is based on perceived health risks that the household water procurer (parent) perceives. The conceptual framework is based on perceived health risk and the water procurer chooses between two technologies, green vs. red wells to protect their own and their child's health. Let effectiveness of using a green well be denoted by $x_g(z_g)$ where z_g denotes the intensity of use. Effectiveness of an accessible technology to reducing arsenic exposure relates to the reduction in associated health risks and depends on intensity of use of the technology. A reduction in exposure to arsenic as a result of actions taken by the household is referred to as mitigating arsenic exposure. Mitigating arsenic exposure α_g is then defined in terms of effectiveness and intensity of use

$$\alpha_g = x_g(z_g)z_g \quad (1)$$

The water procurer chooses the intensity of using a green well at a cost $c_g z_g$, where the cost here is delineated in time spent walking to and from a green well. Let utility be an additively separable, twice continuously differentiable function of household income (W), health of the child (h_s^c) and health of the parent (h_s^p); other utility arguments are assumed to be separable and are suppressed for notational convenience. Health of the child and the parent are functions of mitigating arsenic exposure (α_g), perceived health risk to the child (r_c), perceived health risk to the parent (r_p), the arsenic level in the tubewell water (\bar{r}) and the physical characteristics of child (b_c) and parent (b_p).

The probability that someone in the household will become sick from exposure to arsenic in drinking water is the household's joint density function for two random variables, probability the child will become sick [$\pi_s^c(\alpha_g, r_c, \bar{r}, w)$] and probability the adult will become sick [$\pi_s^p(\alpha_g, r_p, \bar{r}, w)$], such that:

$$\begin{aligned} \pi_s(\alpha_g, r_c, r_p, \bar{r}, w) &= \text{Prob}(\pi_s^c(\cdot), \pi_s^p(\cdot)) \\ &= \sum_{\pi_s^c} \sum_{\pi_s^p} \pi_s(\pi_s^c(\alpha_g, r_c, \bar{r}, w), \pi_s^p(\alpha_g, r_p, \bar{r}, w)). \end{aligned} \tag{2}$$

Here, $\pi_s^c(\alpha_g, r_c, \bar{r}, w)$ is the water procurer's subjective probability of the child's health being in state s_c , and w is opportunity cost of the water procurer's time. Similarly, $\pi_s^p(\alpha_g, r_p, \bar{r}, w)$ is the procurer's subjective probability of their own health being in state s_p . Health states s_c and s_p theoretically represent a set of different health states.

Assuming subjective probabilities are consistent with the Savage subjective probability axioms, parent (water procurer) preferences can be represented by an expected utility function where this expectation is a weighted average of their utility in each realized state (Savage 1954). Parents' subjective probabilities of health state serve as the weights for the utility function with parents choosing the level of intensity (z_g) for arsenic avoidance

$$\text{Max}_{z_g} EU = \sum_s [\pi_s U_s\{W, h_s^c, h_s^p\}] \tag{3}$$

where

$$\pi_s = \pi_s(\alpha_g, r_c, r_p, \bar{r}, w) \tag{3a}$$

$$W = W_0 + G_s - c_g z_g \tag{3b}$$

$$G_s = G_s(\alpha_g, r_c, r_p, \bar{r}, w) \tag{3c}$$

$$h_s^c = h_s^c(\alpha_g, r_c, r_p, \bar{r}, b_c) \tag{3d}$$

$$h_s^p = h_s^p(\alpha_g, r_c, r_p, \bar{r}, b_p) \tag{3e}$$

Household income (W) is conceptually the stream of lifelong income and is equal to money income (I) and wage income (wT), where w is wages and T is time at work ($W = I + wT$). However, in the current application many households do not have wage income and the gains from avoiding arsenic provide more time for the healthy adult and child to provide for the household. In addition, this is a single-period model showcasing averting choice which allows for consideration of lifelong health implications when choosing to mitigate. Thus, lifelong income for the household (W) is a function of initial endowment of wealth (W_0), gains from mitigating arsenic exposure (G_s) and cost of protection activities ($c_g z_g$).

A key departure from the Nastis and Crocker framework is considering the gains from mitigation rather than losses from exposure. Specifically the focus is on gains from mitigating arsenic exposure rather than losses from households' exposure to arsenic. This means that W is what is left over after subtracting the cost of protection activities from the initial endowment of wealth and from gains from mitigating arsenic exposure. Let $G_s = G_s(\alpha_g, r_c, r_p, \bar{r}, w)$ be the household's gains from avoiding exposure to arsenic, which is a function of mitigating arsenic exposure (α_g), the perceived risk level for the child (r_c), the parent's own perceived risk level (r_p), the actual arsenic level in the tubewell water (\bar{r}) and the opportunity cost of parent time (w). Intuitively, gains are an overall measure of better quality of life due to mitigation (e.g. health and productivity benefits). Gains increase at a decreasing rate as arsenic exposure mitigation increases (i.e. $\partial G_s / \partial \alpha_g > 0$ and $\partial^2 G_s / \partial \alpha_g^2 < 0$).

The child health production function is affected by mitigating exposure to arsenic (α_g), perceived ambient risk (r_c), perceived ambient risk level for the parent (r_p), the arsenic level (\bar{r}), opportunity cost of parent's time (w) and physical

characteristics (b_c). The parent's health production function is similar.

This conceptual framework departs from previous research in several important and unique ways:

- the arsenic risk level affects averting behavior, and the child's and the parent's health;
- the child's health (h_s^c) depends on perceived health risks for themselves and perceived health risks for the parent; and
- the parent's health (h_s^p) depends on perceived health risk for themselves and for the child.

These later assumptions recognize a sick parent may not be able to provide as much care for a child as a healthy parent. Similarly, if a child is ill, this can take its toll on a parent's health.

Solving the optimization problem results in three first-order conditions, detailed in the Appendix (available online at <http://www.iwaponline.com/wh/013/213.pdf>). One first-order condition is often called the efficiency condition which is a result of optimizing with respect to level of intensity (z_g). This condition states that parents will take protective actions until the probability weighted marginal benefits from protection equal the marginal cost of protection (c_g). The probability weighted marginal benefits of protection include the effect of mitigating arsenic exposure on: the joint child/parent health probability, gains, child health and parent health. The remaining first-order conditions result in parent willingness to pay for child protection and parent willingness to pay for self-protection. The conditions show parent willingness to pay in terms of child and parent risk effects (and can be seen in more detail as the differential terms showcased in the Appendix); the willingness to pay for child health depends on the expected effect of exogenous risk reduction on child health, while parent willingness to pay for own health depends on the expected effect of exogenous risk reduction on parent health. All three conditions are solved simultaneously to frame the specification of the empirical model.

Empirical model

The previous section presents an analytical structure for a model of households directed at providing valuation of parent and child health risk reductions from arsenic exposure. The efficiency condition used in conjunction

with marginal willingness to pay for avoiding arsenic in their own and their children's drinking water provide empirically testable observable terms. This allows the recovery of valuation of child and parent health through estimates for the observable terms in the empirical framework presented in this section. This research uses an econometric specification similar to the one developed by Saha et al. (1997) and Nastis & Crocker (2007). The theoretical representation (Equations 3(a)–3(e)) form the basis for the structural equations shown in Equations (4) through (7) below. Equation (4) is the linear representation of state-dependent gains from mitigating arsenic exposure (G_s) following from Equation 3(c). Equation (5) is the linear representation of the state-dependent health probability (π_s) following from Equation 3(a). Equations (6) and (7) are the linear representations of the health production functions for child (h_s^c) and parent (h_s^p) following from Equations 3(d) and 3(e) respectively

$$G_s = \gamma_z^G z_g + \gamma_{c_g}^G c_g z_g + \gamma_w^G w + \theta \quad (4)$$

where

$$\theta = R(\cdot)e + \varepsilon \quad (4.1)$$

$$R = \gamma_0 + \gamma_{r_c}^G r_c + \gamma_{r_p}^G r_p + \gamma_r^G \bar{r} + \gamma_{WA}^G + \gamma_{WM}^G \quad (4.2)$$

$$\pi_s = \gamma_{r_c}^\pi r_c + \gamma_{r_p}^\pi r_p + \gamma_z^\pi z_g + \gamma_{c_g}^\pi c_g z_g + \gamma_G^\pi G_s + \gamma_w^\pi w + \gamma_r^\pi \bar{r} + \varepsilon_1 \quad (5)$$

$$h_s^c = \gamma_{r_c}^c r_c + \gamma_{r_p}^c r_p + \gamma_z^c z_g + \gamma_{b_c}^c b_c + \gamma_G^c G_s + \gamma_r^c \bar{r} + \varepsilon_2 \quad (6)$$

$$h_s^p = \gamma_{r_c}^p r_c + \gamma_{r_p}^p r_p + \gamma_z^p z_g + \gamma_{b_p}^p b_p + \gamma_G^p G_s + \gamma_r^p \bar{r} + \varepsilon_3 \quad (7)$$

where the ε are the econometric error terms. Following Saha et al. (1997) state-dependent overall gains from arsenic exposure (G_s) depend on heteroskedastic error term (θ) with $\varepsilon \tilde{N}(0, 1)$ and $e \tilde{N}(\mu, 1)$. Heteroskedastic error term (θ) depends on perceived risk from arsenic exposure and productivity gains from mitigation (R) as described by Equations (4.1) and (4.2). R depends on perceived ambient

risk level for child (r_c) and parent (r_p), actual arsenic levels (\bar{r}) and gains from mitigation γ_{WA}^G (increased work ability) and γ_{WM}^G (increased work chances).

Moving from the theoretical model to the empirical specification (Equations (4)–(7)) requires some clarification with implications for the empirical model. A general limitation here is that the available data are ordered, which is a common occurrence in health data. This means that ambitious assumptions are necessary in identifying dependent variables; the variables used reflect data availability constraints.

First, mitigating arsenic exposure (α_g) is represented by the binary variable z_g in the empirical system of equations, which corresponds to whether a household switches from a red tubewell to a green tubewell. However, some respondents in the sample may already reside next to, and use, a green tubewell without having to switch. Second, the marginal monetary cost of protection (c_g) is represented by fixed cost because the primary averting technology of choice is to use a green tubewell. The only monetary cost, if any, is the cost of establishing the tubewell. However, since many wells in the area are communal or established by government or non-government agency, and since our observations suggest that people tend to walk farther to get water from a green well, walking time is a more appropriate measure of marginal cost. Walking time is used because most water procurers do not have wage income and a suitable household-specific wage rate (opportunity cost of time) is not available.

The probability of health state (π_s) variable is based on responses to a survey question asking whether the water procurer thinks someone in the household will become sick. The rest of the dependent variables, gains (G_s), child health (h_s^c) and parent health (h_s^p) are presented as ordered variables in this analysis. Actual gains from mitigating arsenic exposure are continuous. However, observations from study data indicate respondents' evaluation of expected gains from mitigation in four categories – so the dependent variable, gains, is an ordered categorical variable. The child health variable (h_s^c) is a proxy based on a continuous variable that indicates nutritional status (mid-upper arm circumference [MUAC] in millimeters divided by age). A discrete variable indicating four levels of health status, based on MUAC divided by age, is used because parents may not know the actual circumference of their child's arm in millimeters, but they are told by health workers whether their

child's health is in one of four categories, ranging from poor to good health. It follows that the child's physical characteristics (b_c) (indicated by age from the available data) has to be dropped from the right-hand-side of the estimated child health technology equation (Equation (6)), since age drives the results and washes out all other factors affecting child health. Only ordered data were collected for parent health, where parents evaluated their own health in four categories (see section on summary statistics below for more information).

Endogeneity is expected as the exogenous variables that enter the right-hand-side of Equations (4) through (7) may bring correlations between health inputs and health outcomes. In the behavioral model these inputs are parents' own choices – (e.g., choices for mitigation, immunizations given to children). The final equations were estimated as a system of four equations. Equations (4) through (7) were solved in SAS[®] using the Qualitative and Limited Dependent Variable Model (QLIM) procedure, which analyzes univariate and multivariate limited dependent variable models. QLIM was used to solve four simultaneous probit models.

Both consistency and efficiency can be gained by estimating Equations (4) through (7) jointly. Identification requirements are met since there are more regressors than dependent variables. Also there is at least one regressor in each equation that is not included in the other equations.

Despite the growing literature on ordered response models, ways of accounting for heteroskedasticity are divergent and unclear. Following Greene (2003), a paper by Liao (1994) and the Drichoutis *et al.* (2006) guidelines on interpreting ordered response models, the system of ordered probit models with marginal effects corrected for heteroskedasticity was estimated. A binary probit model was used to estimate Equation (5) while an ordered probit model was used to estimate Equations (4), (6) and (7). The ordered probit model is built around a latent regression model similar in manner to the binary probit model (McKelvey & Zavoina 1975).

DATA

The study site and data collection were undertaken in the context of the International Center for Diarrheal Disease

Research, Bangladesh (ICDDR,B's) long-term cross-sectional and longitudinal research investigating health consequences of arsenic in drinking water in the Matlab (see Figure 1) area of rural Bangladesh (ICDDR,B 2002). According to the British Geological Survey (2001), southeastern Bangladesh, where Matlab is located, is the location in Bangladesh with the most pronounced arsenic contamination of shallow tubewell water. Tubewells that access groundwater are a major source of drinking water in Bangladesh. (Smith et al. 2000).

Data overview: primary and secondary data

Secondary data from an ICDDR, B research initiative exploring health effects of arsenic exposure in the Matlab area were combined with primary data collected for this study. The Matlab area has seven study sub-divisions (A through G) for ongoing research activities. This analysis used a stratified, random sample of the population in Block A (Figure 1). The red dots in Figure 1 denote the locations of tubewells in the study area. Households were stratified based on the concentration of arsenic in the

tubewell they currently used; with stratifications based on high (>50 ppb), medium (25 to ≤50 ppb) and low (<25 ppb) levels of arsenic. Stratification was based on ICDDR,B GIS data mapping tubewells currently in use. The arsenic levels were measured by field kit tests and subsequent laboratory tests (carried out by ICDDR,B). Note that even at low stratification levels, it is possible to find levels in excess of the MCL according to the U.S. EPA- and WHO-recommended guideline of 10 ppb. One thousand respondents were chosen per stratum for a target sample size of 3,000.

The primary data were collected through one time in-person interviews between March and June 2004 under the support of ICDDR,B. For efficient data collection, when an enumerator arrived at a *bari* (a cluster of households who share a common courtyard and whose members are usually patrilineally related) he or she first collected the appropriate family health card. Family health cards of one *bari* are generally kept in one place. The enumerator would then locate the appropriate household (according to the targeted list of respondents) and determine the appropriate respondent: the primary water procurer.

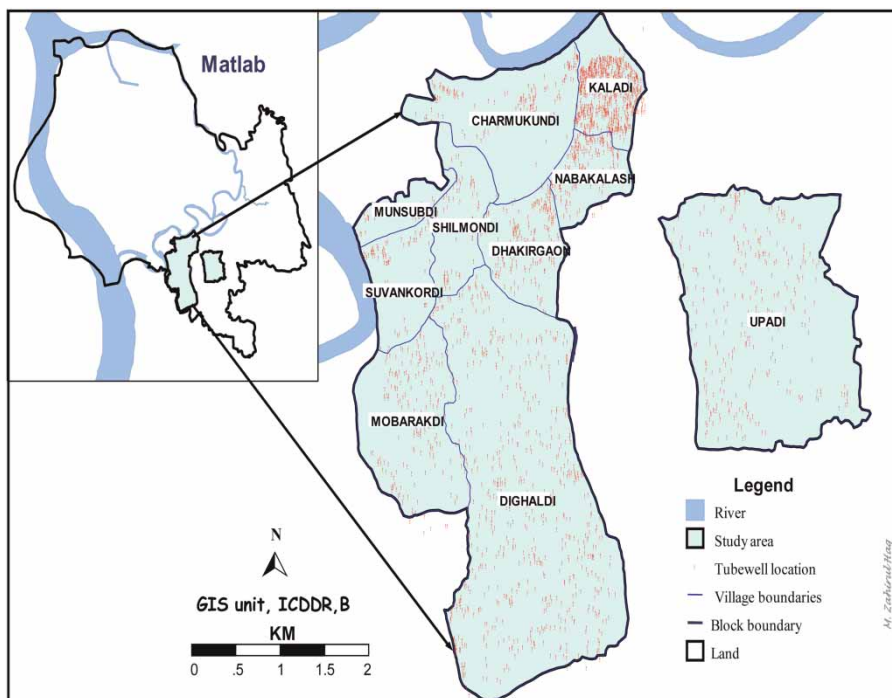


Figure 1 | Tubewell distribution in study area – Block-A in Matlab.

Initially many refusals were encountered due to the heavy time constraints of respondents. In order to increase response rate, the enumerators were instructed to conduct interviews while the household head continued to do household or field work when necessary. For greater efficiency and accuracy, the enumerators gleaned some survey information (such as age of respondent) from the family health card.

The survey was designed to collect data on sociodemographic information, and included questions about individuals' awareness of various issues related to arsenic. Survey questions were also designed to reveal households' past and current sources of drinking water, including questions on arsenic avoidance – respondents were asked if they had switched away from a red tubewell to their current mitigating source. Other questions collected data on health and on safety characteristics (individual, family and community level safety characteristics, e.g. toilet hygiene, cooking hygiene). Lastly, enumerators elicited respondents' willingness to pay for water free from arsenic. The survey was pre-tested by administering the instrument to 40 people outside of the sample area.

Enumerators were able to complete interviews with 2,800 households. Each enumerator had access to the family health card allocated to each household in Matlab. A family health card has provisions to record family characteristics including a unique identification number issued per household member, number of living children, immunization status, health services availed by household members and numerous other health characteristics. Six hundred and ten of the survey respondents could not be linked to ICDDR,B's existing data due to missing data in one or more of the existing secondary data sets, so the usable sample was reduced to 2,190 respondents.

The secondary data were obtained from ICDDR,B records of survey households and included child health indicators (immunizations for diphtheria, tetanus, polio, measles and vitamin supplementation) as well as GIS data.

Summary statistics

The data were utilized to estimate Equations (4)–(7). Table 1 reports dependent variable definitions, coding and descriptive statistics. The survey data provide the variables

Table 1 | Dependent variables ($n = 2,190$)

Variable	Definitions	Descriptive statistics
<i>ProbHealthState</i> (π_s)	1 = Ill health state	34%
	0 = Well health state	66
<i>Gains</i> (G_s)	1 = No gains from mitigating	18%
	2 = Little gains from mitigating	6
	3 = Moderate gains from mitigating	46
	4 = High gains from mitigating	31
<i>ChildHealth</i> (h_s^c)	1 = Acute malnutrition (≤ 110 mm)	57%
	2 = Severe malnutrition (11–125 mm)	38
	3 = Malnourished (125–134 mm)	0
	4 = Normal (> 134 mm)	5
<i>ParentHealth</i> (h_s^p)	1 = Very bad health	4%
	2 = Bad health	38
	3 = Good health	37
	4 = Very good health	20

ProbHealthState (π_s), *Gains* (G_s) and *ParentHealth* (h_s^p), while the secondary health data from ICDDR,B provides the variable *ChildHealth* (h_s^c).

ProbHealthState is a binary variable that represents the water procurer's expected health state for the household. A survey question asks respondents whether someone in their household will become ill from exposure to arsenic in their drinking water; 34% of respondents believed someone in their household would become sick from exposure.

Gains represent household's perceived gains from mitigating arsenic exposure. Gains are an overall measure of better quality of life due to mitigation which could include improved health or productivity benefits. Respondents were asked whether they thought the gain from arsenic mitigation was high, moderate, low or none. Overall, 18% of respondents thought there were no gains and most thought there were moderate gains (46%) or high gains (31%) from arsenic mitigation.

As noted above, *ChildHealth* is indicated by the nutritional status of the child; this is measured by the MUAC of the child in millimeters divided by the child's age. According to Bosch (2005), after being normalized for age, a MUAC greater than 135 mm is considered normal; less than 135 mm is considered malnourished; a MUAC of less than 125 mm is severe malnutrition and a MUAC of less than 110 mm is considered acute malnutrition. Child

health is coded as one of these four categories, and 57% of children had acute malnutrition. While this indicator of child health is not elicited as the parents' subjective perception of their child's health, health workers do inform parents of the health state corresponding to their child's MUAC.

ParentHealth indexes respondent's ratings of own health from 1 through 4. Respondents were asked whether they were in very bad health (1), bad health (2), good health (3) or very good health (4). Overall, 4% reported very bad health, but most reported good health (37%) and very good health (20%).

Table 2 reports the independent variables. The personal interviews collected data for the variables *Avert* (z_g), *PriceAvert* ($c_g z_g$), *TimeAvert* (w), *WorkMore* (R_{WM}), *WorkAbility* (R_{WA}), *ParentRisk* (r_p), *Age* (b_a) and *Male* (b_m), while the ICDDR,B secondary data provide the variables *ChildRisk* (r_c) and *AAS* (\bar{r}).

Table 2 | Independent variables ($n = 2,190$)

Variables	Definitions	Descriptive statistics (range)
<i>Avert</i> (z_g)	1 = Yes 0 = No	34%
<i>PriceAvert</i> ($c_g z_g$)	Cost of averting of tubewell (BDT)	Mean = 178 (0–7,000)
<i>TimeAvert</i> (w)	Walking time to water source (minutes)	Mean = 44 (0–180)
<i>WorkMore</i> (R_{WM})	1 = No increase 2 = Little increase 3 = Moderate increase 4 = High increase	23% 7 41 28
<i>WorkAbility</i> (R_{WA})	1 = No increase 2 = Little increase 3 = Moderate increase 4 = High increase	23% 7 40 29
<i>ChildRisk</i> (r_c)	Vitamin supplementations 1 = Yes 0 = No	88% 12
<i>ParentRisk</i> (r_p)	1 = No 0 = Yes	62% 38
<i>AAS</i> (\bar{r})	Arsenic level ($\mu\text{g/L}$)	Mean = 227 (1–1,019)
<i>Age</i> (b_a)	Age of respondent (years)	Mean = 43 (14–106)
<i>Male</i> (b_m)	Sex of respondent (Male)	22%

BDT = Bangladeshi Taka.

Avert represents a switch away from a red tubewell to a green tubewell, a safe drinking water source. About a third of respondents (34%) switched away from arsenic-contaminated water in a red tubewell: we elicited a binary response on whether the respondents have ever switched from a red tubewell to their current mitigating source. Survey data revealed the prevalent mitigation method in the sampled set of respondents is switching to a green tubewell. Note that some respondents may not need to switch as the tubewell immediately adjacent to their home may be green.

PriceAvert represents the initial cost of switching to a green tubewell. Each respondent reported their share of the cost of installing or reinstalling tubewells, whether it was 0 Bangladeshi Taka (BDT), all of the cost, or a portion of the total cost. The mean initial cost is 178 BDT with a range from 0 to 7,000 BDT.

For respondents switching from a red tubewell to a green tubewell, *TimeAvert* reports the time spent for one trip to gather water from the green tubewell. The time ranged from zero to 180 minutes with a mean of 44 minutes.

About a quarter (23%) of respondents did not think averting arsenic would improve their ability to work (*WorkAbility*) and their chances to work (*WorkMore*). Both of these are ordered categorical variables; respondents were asked to rate their expected changes from 1 through 4, where 1 corresponds to no chance or no increased ability to work, while 4 corresponds to a high increase in chance or ability to work.

ChildRisk is an indicator for perceived arsenic risk for the child. This variable records vitamin A supplementations given to a child. Vitamin A was administered in capsule form for young adults, 100,000 IU for infants aged 6–11 months, and 200,000 IU for children aged 12–59 months. Based on studies that widely posit a negative correlation between arsenic toxicity and vitamin A supplementations (Rao & Avani 2006), and on advice parents are given to protect their child, recorded supplementations given to the child is used as an indicator for subjective arsenic risk level for the child in this research (Hsueh et al. 1995, 1998; Bosch 2005). If parents take their children to the clinic for supplementations, *ChildRisk* = 1. Eighty-eight percent of parents took their child for vitamin A supplementations.

ParentRisk is indicated by a binary variable corresponding to a survey question asking the respondent whether he

or she is concerned about contracting health problems from arsenic in drinking water. Thirty-eight percent were concerned about getting sick from arsenic contaminated water.

AAS depicts the actual arsenic levels found in the tubewell. The arsenic levels are measured by field kit tests and subsequent laboratory tests carried out by ICDDR,B. A simple hydride generation-atomic absorption spectrometry (HG-AAS) method for the determination of arsenic in the range of $\mu\text{g/L}$ to mg/L concentrations in water was used (Wahed et al. 2006). The data show that the average well had an arsenic concentration of $227 \mu\text{g/L}$, which is nearly five times greater than the Bangladesh standard of $50 \mu\text{g/L}$.

The physical characteristics of the respondent are characterized by *Age* and *Male*, indicating gender of the survey respondent. The average age was 43 and 22% were male.

Table 3 presents the explanatory variables for each of the four Equations ((4)–(7)) and the expected signs of coefficients on each variable. A question mark indicates that the expected sign is indeterminate: For example, intuitively we expect to see a positive effect of averting on gains from mitigation, child health and parent health. However the act of averting may be perceived to take more time than is beneficial in productivity or health benefits. People may perceive higher gains from not mitigating as the choice to averting may take more time away from work and time spent walking may be detrimental to their own health, especially if they are starting from a poor health state. Averting could

also potentially take time away from parents to care for their child, resulting in a negative effect on child health.

RESULTS

The results for the simultaneous system of equations conveys, for the most part, a consistent story. At least half of the explanatory variables are statistically significant in each equation (Table 4). All but one of the significant variables have the expected signs, *Avert* in the Gains equation, which indicates that people who have not switched from a red tubewell believe there are greater gains from doing so than those who have switched. Some sampled respondents who have not switched from a red tubewell may already have a green tubewell as their nearest access well, and perceive high gains from remaining at the green tubewell and do not need to switch.

A key result is that time spent averting (*TimeAvert*) increases the perceived *Gains* from mitigation, the expected health status of the household (*ProbHealthState*), and the health status of the child (*ChildHealth*) and the parent (*ParentHealth*). This not only shows that the health of child and parent are improved by averting but that water procurers are both cognizant of benefits of arsenic mitigation and believe that averting arsenic exposure affects the health of their household. It is not straightforward to convert time spent averting into monetary units because many water procurers do not work for wages in Bangladesh but are engaged in necessary sustenance-related activities for the household. However, we can provide some insight of the potential magnitude of time spent in monetary units using the daily wage rate. The monetary equivalent of the opportunity cost of time is evaluated at the mean of *TimeAvert* with an average daily wage rate of 75 BDT or USD1.08 (at 2007 exchange rate) for an unskilled worker in rural Bangladesh (Bangladesh Bureau of Statistics 2004). Assuming a 16 hour day, this translates to a wage trade-off of approximately 7.5 BDT or a sacrifice of approximately 10% of the daily wage rate to gather safe water. It is important to note the value for *TimeAvert* is based on one trip to gather water from a water source safe from arsenic contamination. This suggests that health messages for households to avoid drinking arsenic-contaminated water from red tubewells are having a

Table 3 | Expected signs of explanatory variable coefficients

Variables	Gains	ProbHealthState	ChildHealth	ParentHealth
<i>Avert</i>	+	–	?	?
<i>Gains</i>		–	+	+
<i>PriceAvert</i>	–	+		
<i>TimeAvert</i>	+	–	+	+
<i>WorkMore</i>	+			
<i>WorkAbility</i>	+			
<i>ChildRisk</i>	+	–	?	?
<i>ParentRisk</i>	+	–	?	?
<i>AAS</i>	+	+	–	–
<i>Age</i>				–
<i>Male</i>				?

Table 4 | Coefficient estimates ($n = 2,190$)

Variables	Gains	ProbHealthState	ChildHealth	ParentHealth
<i>Avert</i>	-0.1361*** ^a (0.0456) ^b	0.0215 (0.0666)	-0.1673*** (0.0577)	-0.0280 (0.0438)
<i>Gains</i>		-0.1377*** (0.02006)	0.0126 (0.0355)	0.0589** (0.0307)
<i>PriceAvert</i>	0.00005 (0.00003)	0.00008* (0.00004)		
<i>TimeAvert</i>	0.0023*** (0.0005)	-0.0012* (0.0007)	0.0013** (0.0006)	0.0014*** (0.0006)
<i>WorkMore</i>	0.3720*** (0.0417)			
<i>WorkAbility</i>	0.3269*** (0.0376)			
<i>ChildRisk</i>	0.0134** (0.0062)	0.0043 (0.0093)	-0.0366*** (0.0086)	-0.0084 (0.0081)
<i>ParentRisk</i>	0.0140*** (0.0015)	-0.0093 (0.0103)	0.0070 (0.0116)	0.0053 (0.0086)
<i>AAS</i>	0.00008 (0.00009)	0.0004*** (0.0002)	0.00018 (0.0001)	-0.0003*** (0.0001)
<i>Age</i>				-0.0177*** (0.0017)
<i>Male</i>				-0.0080 (0.0116)
Log Likelihood	-7,670			
AIC	15,441			

^a* Significant at less than 10%, ** less than 5%, *** less than 1%.

^bStandard errors are in parentheses.

behavioral effect on households despite its relatively high premium in time.

It is also interesting to note that parent health risk (*ParentRisk*) did not affect child health (*ChildHealth*) and vice versa. While this is a novel aspect of this model, the empirical results do not suggest that a parent in poor health is less

able to provide for the health of a child than a parent in good health. Likewise, a child with health risks does not appear to diminish parent health.

Table 5 presents heteroskedasticity corrected marginal effects on the highest ordered variable. These marginal effects suggest *TimeAvert* has the largest effect on

Table 5 | Marginal effects^a

Variables	Gains	ProbHealthState	ChildHealth	ParentHealth
<i>Avert</i>	-0.05	0.01	-0.08	-0.003
<i>Gains</i>		-0.06	0.006	0.07
<i>PriceAvert</i>	0.00002	0.00003		
<i>TimeAvert</i>	0.0009	-0.0005	0.0006	0.002
<i>WorkMore</i>	0.14			
<i>WorkAbility</i>	0.12			
<i>ChildRisk</i>	0.005	0.002	-0.018	-0.009
<i>ParentRisk</i>	0.005	-0.005	0.003	0.006
<i>AAS</i>	0.00003	0.0002	0.00009	-0.0003
<i>Age</i>				-0.002
<i>Male</i>				-0.0009

^aThe effects of changes in independent variables in an ordered probit model are not easy to interpret. Keeping in mind that care must be taken in interpreting the coefficients that come from an ordered probit, marginal effects must be computed as partial derivatives for continuous variables and discrete changes must be computed for effects of binary variables (Greene 2003). For binary variables the interpretation is the increase or decrease in probability that the dependent variable takes on the value of 1 if the binary variable is 1. The marginal effects for the continuous variables can be interpreted as the approximate increased or decreased probability that the dependent variable takes on the value of 1, given one more unit of the explanatory variable, with other explanatory variables held at their mean. Even with these extra calculations researchers warn that marginal effects should be used with caution and for an overall impression only (Liao 1994).

ParentHealth, followed by household *Gains*. *WorkMore* and *WorkAbility* have similar effects on *Gains*, and this is also true for *ChildRisk* and *ParentRisk*, suggesting that subjective notions of improved health or health risk concerns for child and self increase the probability of higher overall gains from mitigation. Clearly an improved ability to work and increased opportunities to work translate to improved monetary benefits and directly affect people's notions of higher gains from mitigation. The benefits from mitigation are also felt through improved health and health risks for self and child. All of the effects support the notion that villagers who perceive higher risks from arsenic in drinking water are likely to take actions to reduce their exposure.

DISCUSSION

We did not initially think that risk-taking behavior of the household would support the notion that people avert in response to contaminated drinking water, particularly when most respondents in this study experience chronic long-term arsenic exposure, which typically does not present with symptoms that are immediately severe. Given the long dose-response relationship of arsenic to health risk, severe health consequences may take time to build, and since having higher than permissible arsenic levels in respondents' drinking water does not present imminent health effects to the household, the average villager may not choose to avert. However, the results show that people do respond to safe drinking water programs, despite the high opportunity cost of doing so. The most compelling part of this story seems to imply that despite the high premium of time spent averting this is perceived to improve health and overall benefits from mitigation. Time spent averting, 44 minutes on average for each water collection trip, takes time away from activities providing sustenance for the household, visiting health care facilities and other important household tasks. On the other hand, the time spent averting increases perceived work benefits as outcomes of mitigation. Households seem to place a high value on protecting health notwithstanding day-to-day concerns of fulfilling household tasks. Overall, this analysis suggests public health mitigation policies are contributing to improved health by

motivating people to avert at the expense of valuable time away from work providing for household sustenance. Because increased work productivity has such a significant impact on self-rated gains from arsenic mitigation, policy makers should take into account that mitigating activities should be developed and promoted with a focus on reducing time spent averting. This may argue for wellhead mitigation technologies which would make convenient but contaminated wells viable again as a water source.

The motivation for averting arsenic exposure is enhanced by the presence of children in the household. One of the key aspects of this paper is the assumed reciprocity of parent and child health. Children are particularly susceptible to arsenic in drinking water and public health directives on remediation of arsenic would purportedly have a strong effect on child health. Furthermore, public health awareness campaigns may benefit not only by highlighting health consequences for children from arsenic contamination in drinking water, but by highlighting the adverse effects that trickle down to affect children's health from adults' exposure to arsenic contaminated water. This is particularly relevant for pre- and post-natal health care (e.g. supplementations taken during pregnancy, breast milk feeding practices) and may speak to targeting women in public health awareness campaigns. The health of water procurers (typically the mother) is important in this regard as this may affect intensity of averting, which in turn would affect child health. On the other hand, a child who is ill may adversely affect the health of the water procurer (time and energy spent in taking care of a sick child). However, the assumed reciprocity of parent and child health is not borne out by the empirical analysis. In terms of child-to-parent health reciprocity, a parent in rural Bangladesh, who typically has to care for many children, may not have the luxury of devoting much time or energy to take care of one sick child. In terms of parent-to-child health reciprocity, this may mean despite poor parent health, intensity of averting is not affected. A future direction for work in this context points to relative valuation of child versus parent health.

The model of stochastic decision-making linking parent health and child health outcomes can be used to frame the relative valuation of child and parent health, particularly in a developing country context. Willingness to pay studies

that look at the relative valuation of child over parent health in relatively affluent countries show that parents tend to value their child's health higher than their own. Agee & Crocker (2008) show parents' valuation of their children's health exceeds the valuation of their own by 1.5–1.7 percentage points, while Dickie & Gerking (2003) found that parents are willing to accept a more than two-fold increase in risk of skin cancer to themselves in return for lowering this risk to their children by one percentage point on average. The relative estimates for parent and child health reported above and other studies also suggest that at-risk parents value their child's health significantly higher than their own (Dockins *et al.* 2002; Dickie 2004). Would this hold in a heavily resource-constrained context? In rural Bangladesh children help provide the sustenance for the households, which is not the case for the United States applications cited above, and Bangladeshi households have more children on average than do households in the United States. A future question we can ask going forward is whether or not parents value their child's health more than their own when they are in a developing country context.

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