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VALUATION OF AVOIDING ARSENIC IN DRINKING WATER IN RURAL BANGLADESH: AN AVERTING BEHAVIOR ANALYSIS

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Abstract: Widespread arsenic contamination of groundwater in Bangladesh places the health of millions of Bangladeshis in jeopardy. Ninety-five percent of the population of Bangladesh is estimated to rely on groundwater for drinking purposes and naturally occurring arsenic contaminates over a fourth of the groundwater in Bangladesh. Mitigation and avoidance of arsenic contaminated water is a complex and expensive prospect for Bangladeshi villagers. Water sources without high arsenic levels are scarce, taking a practical toll on a person's time available for work and other activities when they have to seek safe water to drink. Research suggests that children are particularly susceptible to chronic arsenic exposure. Since children live with parents who are the primary decision makers for sustenance, a model of decision-making linking parent health and child health outcomes is used to frame the relative valuation of child and parent health using an averting behavior model. Because the decision maker does not have deterministic knowledge of whether they or their children will be ill, drinking water choices are framed in a stochastic framework. Relative valuation of child health over own health reveal that even with heavy resource constraints, parents value their child's health more than twice as much as their own health. The results can help evaluate whether public health mitigation policies to reduce exposure to arsenic in drinking water are working, and examine whether factors such as child health and time required for remediation have an effect on mitigation measures.

1. Introduction

Rural households in developing countries may not always have the option of taking protective actions in response to public health crises. In this context, good health outcomes 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. This paper investigates how parents in a developing country react to public health warnings, and uses this to frame parent's valuation of their child's health. Little research has been done to investigate the value that parents place on their child's health. This paper builds on this work and improves previous studies by allowing child health to affect parent health and vice versa.

The model is based on rural Bangladeshi household responses to elevated levels of arsenic in drinking water from tubewells. 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). Though the figures are yet to be confirmed, 30-40 million people in Bangladesh are estimated to be at risk of arsenic poisoning from drinking water contaminated with arsenic levels in excess of 50 ppb or μg/L (Tibbets, 2004). ICDDR,B (International Center for Diarrhoeal Disease Research, Bangladesh) is conducting an ongoing research effort to investigate health consequences of arsenic in drinking water in one of the affected areas of rural Bangladesh, Matlab (ICDDR,B, 2002). According to the British Geological Survey (2001), southeastern Bangladesh, where Matlab is located, is the part of the country with the most pronounced arsenic contamination of shallow tubewell water.

This paper investigates decisions to avoid arsenic exposure in Matlab, and estimates the value Bangladeshi villagers may place on reducing perceived arsenic risk for their children relative to the value they place on reducing perceived arsenic risk for themselves. Arsenic mitigation technologies are expensive, and water sources with low levels of arsenic may be few and far between, taking a practical toll on a person's time available for work at home or outside of the home. The decision to mitigate may be influenced by convenient remediation options and/or by individual household characteristics such as the health of children in the household. Since time may be a crucial driving force behind individuals' decisions to avoid arsenic exposure for their household, the valuation is framed in terms of time.

Household responses to elevated levels of arsenic in drinking water from tubewells are examined using averting behavior in a household production model. Averting behaviors are protective expenditures or actions that individuals undertake to avoid exposure to any undesirable outcome (e.g. pollution, illness, death), revealing something about the value of avoiding environmental damage. Wider applications of the averting behavior approach are limited by incomplete control for joint production – where averting behaviors indivisibly affect more than one outcome. The assumption in the averting behavior approach in this study is that people make defensive choices in order to maximize their level of well being when faced with increased health risks associated with exposure to arsenic contaminated drinking water (Cropper and Oates, 1992). Values for avoiding exposure to arsenic are inferred by examining choices of drinking water (assuming one member of the household acts of behalf of the entire household). These values allow investigation of implied values for individual household members such as children.

The goal of this research is to investigate choices of drinking water in rural Bangladesh and to delineate private values of parent and child health by exploring decisions to reduce exposure to arsenic in household water supplies. The objectives are to:

- investigate household responses to elevated levels of arsenic using averting behavior in a household production framework;
- estimate parent willingness to pay for reduced risk from arsenic exposure in themselves and their children; and
- estimate welfare effect based on relative valuation of parent and child health for reduced risk from arsenic exposure.

2. Literature Review

Multiple valuation approaches can be used to estimate the values people place on reducing exposure to arsenic contaminated water. Prior research has used both averting behavior and stated-preference methods to value water quality. This study uses an averting behavior approach in a household production framework. There is extensive empirical and theoretical work on averting behavior using the household production framework (HPM) (Abdalla 1994; Bartik 1988; Cropper 1981; Dickie 2003; Grossman 1972; Whitehead et al. 1998). Comparatively less work exists on averting behavior in HPM with a focus on relative valuation of child and parent health.

Conceptually, the averting expenditures necessary for complete avoidance is a correct measure of the willingness to pay to avoid arsenic exposure. This approach is difficult to implement since people may not be able to fully avert, in other words, averting will not necessarily return people to their original health state. Also, theoretically correct measures of WTP could be estimated using averting expenditures if information of the household production technology was available (Bartik, 1988). Without specific information on the household production technology, as is likely in this and other health related research, lower bounds to WTP could be obtained from averting expenditure information for marginal changes in pollution.[1]

Averting behavior is largely dependent on perception of ambient risk. According to Smith (1986), subjective risk, not objective risk determines individual valuations of safety. Slovic et al. (1980) also find that people respond to the hazards they perceive, not actual hazard levels. These findings are corroborated in a number of averting behavior studies focused on risk from drinking water. For example, Abdallah, Roach and Epp (1992) find households are more likely to take defensive actions if they perceive increasing health risks from contamination or have children in the

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[1] Bartik also noted that the capability of averting expenditures estimates to bound WTP depends on assumptions made – such as jointness. Averting inputs should not exhibit jointness in the production of household outputs. If jointness is violated by an averting good, expenditures on the good are theoretically divided among the production of each commodity involved.

household. Abrahams et al. (2000) also support findings of subjective versus objective risk driving averting actions in a model of averting behavior in response to water contamination risks. The empirical work showing importance of subjective risk frames the use of perceived risk to value child health in this paper.

Focusing on a household decision-maker's perception of arsenic risk levels, the problem of arsenic hazard mitigation under uncertainty is represented, following the endogenous risk framework of Ehrlich and Becker (1972) and Quiggin (2002). In the Ehrlich and Becker study, market insurance, self-insurance and self-protection are defined as three mitigation measures where self-insurance is defined as a reduction in the magnitude of the loss from the hazard and self-protection is a reduction in the probability of the loss from the hazard. Quiggin further extends the study to incorporate utility maximization of an individual over a wide range of hazard mitigation activities with different probability-contingent effects, where individuals' mitigating actions can alter both the probability and severity of any realized health effect. Quiggin's model is extended in this research by incorporating a unitary framework and by embedding the individual's utility maximizing choice of arsenic mitigation activity in a household context, allowing for derivation of willingness to pay for self and child to avert the arsenic hazard.

While several empirical studies examine parental values for own and child health, few analytically link parents value of own health to the value they attach to their child's health (Agee and Crocker, 1996; Carlin and Sandy, 1991; Grossman and Joyce, 1990; Rosensweig and Schultz, 1983, 1988; Viscusi et al., 1987). Agee and Crocker explicitly model the link between parents value of own health to child health values in two studies. This means the models allow derivation of expressions linking the values households attach to own and child health, which is a critical component of this study. Based on choices parents make to obtain health services (Agee and Crocker, 2005); and to reduce environmental tobacco smoke exposure for their children (Agee and Crocker, 2007) parental willingness to pay for own and child health are derived – the ratio of these marginal willingness to pay estimates reveal parent's marginal rate of substitution between own and child health. Empirical results reveal parents marginal valuations of child health are nearly twice as large as parent's valuations of own health (Agee and Crocker, 2005) and mothers who smoke value improvements in their child's health 1.5-1.7 times higher than equivalent improvements in their own health (Agee and Crocker, 2007).

The above studies explicitly explored the analytical link between child and parent health, and thus, were crucial in guiding this research. In this paper the model is designed to produce expressions linking the values household adults attach to reductions in perceived arsenic risk levels to themselves and their children. However, most of the above models' willingness to pay estimates are not affected by time allocations which may be an important element of this research. Time is presumably a significant component of all averting behavior studies – but may be crucial in developing country applications - not only as an endogenous input in the production process but also in estimating welfare effects. The nature of valuation for perceived risk reductions for people whose economic life is only partly or even slightly participative in a cash market economy may be expressed through investments in time rather than purchased inputs.

Hoque et al. (2004), Ahmad et al. (2002) and Aziz et al. (2006), 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 enforces the importance of incorporating the value of time in any study that works with rural areas and time constrained respondents. Another arsenic study in rural Bangladesh uses contingent valuation survey data to investigate willingness to pay for arsenic free drinking water (Ahmad et. al, 2005) while the research in this paper investigates protective actions parents take to avoid arsenic exposure for themselves and their children.

3. Theoretical Model and Empirical Framework

This model builds upon the endogenous risk framework of Ehrlich and Becker (1972) and uses a simple household production framework to characterize activities that may offer protection from arsenic exposure. A representative household decision maker is assumed to allocate family resources to maximize utility of an altruistic parent, an assumption used by most research involving economics of the family (Becker, 1981; Behrman, Pollack and Taubman, 1995). Also, only one child is included in the model, allowing the analysis to focus on the choices parents make in the trade-offs between risks for themselves and their children (Dickie and Gerking, 2002; Pitt, Rosenzweig and Hassan, 1990; Rosenzweig and Schulz, 1983).

The conceptual framework in this paper uses a model developed by Nastis and Crocker (2007) that allows estimation of parents valuation of own and child health. This paper imposed additional structural assumptions that allow derivation of willingness to pay measures to reduce perceived health risks without unobservable utility terms while Nastis and Crocker employ a spanning set of protection activities to derive observable marginal willingness to pay measures.

Model Structure

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 from a finite set technologies or activities to protect themselves and their children from the health hazards posed by arsenic in their drinking water. Arsenic poses only a health hazard; it does not affect the taste or smell of water (US EPA, 2007). It is also assumed mitigation technologies do not affect the palatability of the drinking 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 occurs because a technology is not used either because the household decision maker is unaware of a technology or lacks the resources to obtain the mitigation technology. Effectiveness of an accessible technology depends on the intensity of use where effectiveness of mitigation increases at a decreasing rate with respect to intensity. Lack of access implies zero intensity and zero cost of mitigation. Household members do not know whether they will be ill or well. Thus the theoretical specification is based on health risks that the household decision makers (parents) perceive. This, in conjunction with an additively separable utility function allows derivation of marginal willingness to pay for own and child health.

The conceptual framework allows the household decision maker to choose from among a finite set of K technologies. Let effectiveness of a given technology k be denoted by $x_k(z_k)$ where z_k denotes the intensity of use of technology k. Mitigating arsenic exposure α_k is then defined in terms of effectiveness and intensity of use of technology k as follows:

$$\alpha_k = x_k(z_k)z_k . \qquad (1)$$

The representative household decision maker chooses the intensity of any given technology, z_k, at a cost $p_k z_k$. 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^m) where health of child and parent are a function of mitigating arsenic exposure (α_k), perceived health risk to the child (r_c), perceived health risk to the parent r_m, actual arsenic levels in tubewell water ($\bar{r}$) and child (b_c) and parent phenotype (b_m).

Since individuals do not know whether they or members of their household will be in a sick health state the parent's objective function is presented in an expected utility framework.

$\pi_s(\alpha_k, r_c, r_m, \bar{r}, w)$ is the households joint density function for the two random variables $\pi_s^c(\alpha_k, r_c, \bar{r}, w)$ and $\pi_s^m(\alpha_k, r_m, \bar{r}, w)$ so that:

$$\pi_s(\alpha_k, r_c, r_m, \bar{r}, w) = \text{Prob}(\pi_s^c(.), \pi_s^m(.)) = \sum_{\pi_s^c}\sum_{\pi_s^m}\pi_s(\pi_s^c(\alpha_k, r_c, \bar{r}, w), \pi_s^m(\alpha_k, r_m, \bar{r}, w)) \qquad (2)$$

$\pi_s^c(\alpha_k, r_c, \bar{r}, w)$ is the representative household decision maker's subjective probability of a child's health being in state s_c, $s_c = 1, \ldots\ldots S_c$ states of health, where r_c is the perceived arsenic hazard level for the child, $\bar{r}$ is actual arsenic level in tubewell water and w is opportunity cost of parent's time. Also $\pi_s^m(\alpha_k, r_m, \bar{r}, w)$ is the household decision maker's subjective probability of own health being in state s_m, $s_m = 1, \ldots\ldots S_m$ states of health, where r_m is the perceived arsenic risk level for the parents and $\bar{r}$ is the actual arsenic level in tubewell water. The simplest case of two health states is assumed for the model, one state represents good health while the second state represents bad health.

Assuming subjective probabilities are consistent with the Savage subjective probability axioms, parent 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_k of technology k:

$$\underset{z_k}{Max}EU = \sum_s[\pi_s(\alpha_k, r_c, r_m, \bar{r}, w)U_s\{W_0 - p_k z_k + G_s(\alpha_k, r_c, r_m, \bar{r}, w), h_s^c(\alpha_k, r_c, r_m, \bar{r}, b_c), h_s^m(\alpha_k, r_c, r_m, \bar{r}, b_m)\}]$$

where

$$\pi_s = \pi_s(\alpha_k, r_c, r_m, \bar{r}, w) \qquad (3)$$

$$W = W_0 + G_s(\alpha_k, r_c, r_m, \bar{r}, w) - p_k z_k \qquad (4)$$

$$G_s = G_s(\alpha_k, r_c, r_m, \bar{r}, w) \qquad (5)$$

$$h_s^c = h_s^c(\alpha_k, r_c, r_m, \bar{r}, b_c) \qquad (6)$$

$$h_s^m = h_s^m(\alpha_k, r_c, r_m, \bar{r}, b_m) \qquad (7)$$

Household income (*W)* is defined differently from Nastis and Crocker (2007). Conceptually, (*W)* is the stream of lifelong household 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).* Stream of lifelong income for the household (*W)* is a function of initial endowment of wealth (W_o), gains from mitigating arsenic exposure (G_s) and cost of protection activities $p_k z_k$. Another departure from Nastis and Crocker is an alternate mitigation structure – the effect of mitigation is defined in terms of 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, so 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 $G_s = G_s(\alpha_k, r_c, r_m, \bar{r}, w)$ be the household's gains from avoiding exposure to arsenic, where gains is dependent on mitigating arsenic exposure (α_k), the child's perceived risk level (r_c), the parents perceived risk level (r_m), the actual arsenic risk level ($\bar{r}$) and on the opportunity cost of parent's time (w). Intuitively, Gains is an overall measure of better quality of life due to mitigation (e.g. health and productivity benefits). Gains increase at a decreasing rate with mitigating arsenic exposure so that $\frac{\partial G_s}{\partial \alpha_k} \succ 0$ and $\frac{\partial^2 G_s}{\partial {\alpha_k}^2} \prec 0$.

The child's level of health production is a function of mitigating exposure α_k, perceived ambient risk for self (r_c), perceived ambient risk levels from arsenic exposure for the parent (r_m), actual arsenic risk levels ($\bar{r}$) and on the opportunity cost of parent's time (w). The parents level of health production is a function of mitigating exposure (α_k), perceived ambient risk for self (r_m), perceived ambient risk levels from arsenic exposure for the child (r_c), actual arsenic risk levels ($\bar{r}$) and on the opportunity cost of parents time (w). Also a departure from Nastis and Crocker's original theoretical construct is the hypothesis that actual arsenic risk levels affect averting behavior and health, and that child health (h_s^c) depends not only on perceived health risks for child but also on perceived health risks for parent. Similarly, parent health (h_s^m) depends not only on perceived health risk for themselves but also on perceived health risk for their children. This assumption is made since parent health can affect child health as a child can receive less attention from a parent who is ill. 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 (See Appendix for detailed derivations). One first order condition is often called the efficiency condition which is a result of maximizing the objective function with respect to level of intensity z_k of technology k. This condition states that parents will take protective actions until the probability weighted marginal benefits (left hand side) equals the marginal cost of each protection activity p_k (right hand side).

$$\frac{1}{E\lambda}\left[\sum_s \frac{\partial \Pi_s}{\partial \alpha_k} U_s(x_k'(z_k)(z_k)+x(z_k)) + \sum_s \Pi_s \frac{\partial U_s}{\partial W}\frac{\partial G_s}{\partial \alpha_k}(x_k'(z_k)(z_k)+x(z_k)) + \sum_s \Pi_s \frac{\partial U_s}{\partial h_s^c}\frac{\partial h_s^c}{\partial \alpha_k}(x_k'(z_k)(z_k)+x(z_k)) + \sum_s \Pi_s \frac{\partial U_s}{\partial h_s^m}\frac{\partial h_s^m}{\partial \alpha_k}(x_k'(z_k)(z_k)+x(z_k))\right] = p_k \tag{8}$$

where $\frac{1}{E\lambda} = \sum_s \Pi_s \frac{\partial U_s}{\partial W}$ [2]

The efficiency condition can be rewritten with the alpha partial derivatives represented by the γ_α vectors, and the unobservable utility terms represented by the ξ vectors:

$$\left[\gamma_\alpha{}^1 \gamma_\alpha{}^2 \gamma_\alpha{}^3 \gamma_\alpha{}^4\right] \underbrace{\begin{bmatrix} \xi^1 \\ \xi^2 \\ \xi^3 \\ \xi^4 \end{bmatrix}}_{Utility_{Terms}} = p_k \tag{9}$$

where $\gamma_\alpha{}^1$ = Effect of mitigating arsenic exposure on health probability.
$\gamma_\alpha{}^2$ = Effect of mitigating arsenic exposure on gains.
$\gamma_\alpha{}^3$ = Effect of mitigating arsenic exposure on child health.
$\gamma_\alpha{}^4$ = Effect of mitigating arsenic exposure on parent health.

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[2] $\frac{1}{E\lambda}$ is the expected marginal utility of income.

The second first order condition where parent WTP for child protection is derived is a result of maximizing the objective function with respect to ambient risk for child. Then, solving for that change in mitigating arsenic exposure α_k which holds utility constant, and rearranging terms parents' marginal willingness to pay for an exogenous risk reduction for the child ($-\frac{\partial W}{\partial r_c}$) is obtained, with the perceived ambient risk for child (r_c) partial derivatives represented by the γ_{r_c} vectors, and the unobservable utility terms represented by the ξ vectors:

$$-\frac{\partial W}{\partial r_c} = \left[\gamma_{r_c}{}^{\pi} + \gamma_{r_c}{}^{G} + \gamma_{r_c}{}^{c} + \gamma_{r_c}{}^{m}\right] \underbrace{\begin{bmatrix} \xi^1 \\ \xi^2 \\ \xi^3 \\ \xi^4 \end{bmatrix}}_{Utility_{terms}} \tag{10}$$

By symmetry, the third first order condition showing parent's marginal willingness to pay for an exogenous risk reduction for themselves ($-\frac{\partial W}{\partial r_m}$) can be derived, where the parent's marginal willingness to pay for an exogenous risk reduction for themselves can be rewritten with the perceived ambient risk for self (r_m) partial derivatives represented by the γ_{r_m} vectors, and the unobservable utility terms represented by the ξ vectors:

$$-\frac{\partial W}{\partial r_m} = \left[\gamma_{r_m}{}^{\pi} + \gamma_{r_m}{}^{G} + \gamma_{r_m}{}^{c} + \gamma_{r_m}{}^{m}\right] \underbrace{\begin{bmatrix} \xi^1 \\ \xi^2 \\ \xi^3 \\ \xi^4 \end{bmatrix}}_{Utility_{terms}} \tag{11}$$

Equations 10 and 11 contain observable and unobservable utility terms where the column vectors contain unobservable utility terms. In order to recover marginal willingness to pays without unobservable utility terms, the efficiency condition (equation 9) can be used by arranging the α partial derivatives into a vector ψ_α. The resulting ratio of equation 10 over 11 can be recovered without unobservable utility terms from the empirical framework.

$$\frac{-\frac{\partial W}{\partial r_c}}{-\frac{\partial W}{\partial r_m}} = \frac{\psi_{r_c}}{\psi_{r_m}} = \frac{\left[\gamma_{r_c}{}^{\pi} + \gamma_{r_c}{}^{G} + \gamma_{r_c}{}^{c} + \gamma_{r_c}{}^{m}\right]}{\left[\gamma_{r_m}{}^{\pi} + \gamma_{r_m}{}^{G} + \gamma_{r_m}{}^{c} + \gamma_{r_m}{}^{m}\right]} \tag{12}$$

The theoretical relative welfare effect frames this evaluation at the expected marginal utility of income. Let $MWTP^{m}_{r_c,r_m}$ be the parent's conditional welfare effect. Weighted by the expected marginal utility of income this can be computed from the estimates of equation 12.

$$MWTP^{m}_{r_c,r_m} = \frac{-\frac{\partial W}{\partial r_c}}{-\frac{\partial W}{\partial r_m}} * \frac{1}{E\lambda} \tag{13}$$

Since respondent resources are more likely to be constrained by opportunity cost of time rather than by income in rural Bangladesh, the empirical framework evaluates the welfare measure at the opportunity cost (*w)* of mean time spent averting ($\overline{T}$) rather than the expected marginal utility of income ($\frac{1}{E\lambda}$). A parent's conditional welfare effect of a marginal decrease in relative risk level for child over self is approximated by equation 14.1.

$$MWTP^{m}_{r_c,r_m} = \frac{\psi_{r_c}}{\psi_{r_m}} w\overline{T}\ . \tag{14.1}$$

Empirical Models

This is a stochastic model where the risk framework is endogenous, so that the health production functions include risk and averting risk as inputs. Since health outcomes are directly affected by activities of health production, this research presents an econometric specification similar to the one developed by Saha et al. (1997) and Nastis and Crocker (2007).

Equation 15 is the linear representation of the state dependent health probability π_s, mapped to the unit circle. Equation 16 is the linear representation of gains from mitigating arsenic exposure G_s. Equations 17 and 18 are the linear representations of the health production function for child h_s^c and health production function of parent h_s^m.

$$\pi_s = \gamma_{r_c}^{\pi} r_c + \gamma_{r_m}^{\pi} r_m + \gamma_{\alpha}^{\pi} \alpha_k + \gamma_{p_k}^{\pi} p_k z_k + \gamma_G^{\pi} G_s + \gamma_w^{\pi} w + \gamma_r^{\pi} \bar{r} + \varepsilon_1 \tag{15}$$

$$G_s = \gamma_{\alpha}^{G} \alpha_k + \gamma_{p_k}^{G} p_k z_k + \gamma_w^{G} w + \gamma_r^{G} \bar{r} + \theta \tag{16}$$

$$h_s^c = \gamma_{r_c}^{c} r_c + \gamma_{r_m}^{m} r_m + \gamma_{\alpha}^{c} \alpha_k + \gamma_{\rho_c}^{c} \rho^c + \gamma_G^{c} G_s + \gamma_r^{c} \bar{r} + \varepsilon_2 \tag{17}$$

$$h_s^m = \gamma_{r_c}^{m} r_c + \gamma_{r_m}^{m} r_m + \gamma_{\alpha}^{m} \alpha_k + \gamma_{\rho_m}^{m} \rho^m + \gamma_G^{m} G_s + \gamma_r^{m} \bar{r} + \varepsilon_3 \tag{18}$$

This constructed empirical system is modified to accommodate limitations of the available data. First, mitigating arsenic exposure α_k, is represented by the binary variable z_k in the empirical system of equations. z_k corresponds to a survey question asking the respondent whether he or she averts. Second, the marginal cost of protection p_k is empirically represented by fixed cost rather than variable cost. Survey data reveal the primary averting technology of choice is use of a green tubewell and costs for green tubewells are costs of establishing the tubewell rather than marginal cost of maintenance. Since people tend to walk farther to get water, walking time as the marginal cost is more appropriate. Walking time is put in as a time variable because a suitable household specific wage rate (opportunity cost of time) is not available.

Health data available constrains the empirical system and health production technologies to current health state for child and parent. The probability of health state (π_s) corresponds to a question asking the respondent whether he or she thinks someone in the household will be sick. Child health (h_s^c), along with parent health (h_s^m) and Gains (G_s) are presented as ordered variables in this analysis. Although actual child health (h_s^c) is a continuous variable as indicated by nutritional status (MUAC - mid upper arm circumference in millimeters), estimations include child health as a discrete variable with lower ordered values indicating poor nutritional status while higher ordered values indicate better nutritional status. The reason for this is parents may not know the actual circumference of their child's arm in millimeters but they are told by health workers whether their child is in poor health in four categories ranging from poor to good health. Reduced form equations reflect constraints of available data.

Reduced Form Equations

The reduced form equations 19 through 22 follow from the econometric specification and empirical system modification due to data limitations. Following Saha et. al (1997) state dependent overall gains from arsenic exposure (G_s) depend on heteroskedastic error term (θ) with $\varepsilon \sim N(0,1)$ and $e \sim N(\mu,1)$. Heteroskedastic error term θ depends on perceived risk from arsenic exposure and productivity gains from mitigation (*R)* as described by equations 19.1 and 19.2. *R* depends on perceived ambient risk level for child r_c and parent r_m, actual arsenic risk levels $\bar{r}$ and work gains from mitigation γ_{WA}^G (increased work ability) and γ_{WM}^G (increased work chances).

$$G_s = \gamma_z^G z_k + \gamma_{p_k}^G p_k z_k + \gamma_w^G w + \theta \tag{19}$$

$$\text{where} \quad \theta = R(.)e + \varepsilon \tag{19.1}$$

$$R = \gamma_0 + \gamma_{r_c}^G r_c + \gamma_{r_m}^G r_m + \gamma_r^G \bar{r} + \gamma_{WA}^G + \gamma_{WM}^G \tag{19.2}$$

$$\pi_s = \gamma_{r_c}^\pi r_c + \gamma_{r_m}^\pi r_m + \gamma_z^\pi z_k + \gamma_{p_k}^\pi p_k z_k + \gamma_G^\pi G_s + \gamma_w^\pi w + \gamma_r^\pi \bar{r} + \varepsilon_1 \tag{20}$$

$$h_s^c = \gamma_{r_c}^c r_c + \gamma_{r_m}^m r_m + \gamma_z^c z_k + \gamma_G^c G_s + \gamma_r^c \bar{r} + \varepsilon_2 \tag{21}$$

$$h_s^m = \gamma_{r_c}^m r_c + \gamma_{r_m}^m r_m + \gamma_z^m z_k + \gamma_{\rho_m}^m \rho^m + \gamma_G^m G_s + \gamma_r^m \bar{r} + \varepsilon_3 \tag{22}$$

4. Data

Identification and Estimation Strategies

Endogeneity is expected as the exogenous variables that enter the right hand side of equations 19 through 22 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). Although consistency may be achieved by employing 2SLS, it ignores the reduced form restrictions implied by the theoretical model (Court, 1973; Rosensweig and Schultz, 1983). Both consistency and efficiency can be gained by putting together the reduced form equations and estimating them jointly as a system. Identification requirements are met since there are more regressors than dependent variables. Also there is at least one regressor that is not included in the other regressions.

The binary probit model is used to estimate equation 20 and the ordered probit model is used to estimate 19, 21 and 22. The ordered probit model is built around a latent regression model similar in manner to the binary probit model (McElvey and Zavoina, 1975). As in the binary probit model (which is the special case of J=1), the mean and variance of ω is normalized to zero and one. Greene (2003) specifies the following general model:

$y^* = \beta' x + \omega$ where the explained variable y^* is usually unobserved, β is the vector of parameters to be estimated and *x* is the vector of explanatory variables. The heteroskedastic regression model in this study is estimated using the log likelihood function *l*:

$$l = -\frac{N}{2}\ln(2\pi) - \sum_{n=1}^{N}\frac{1}{2}\ln(\sigma_i^2) - \frac{1}{2}\sum_{n=i}^{N}(\frac{e_i}{\sigma_i})^2 \tag{23}$$

where the error term and the variance θ of regression disturbance is specified by

$$e_i = y_i - x_i'\beta \tag{24}$$

$$\sigma_i^2 = \sigma^2 \exp(\eta_i'\delta) \tag{25}$$

N is the number of observations in the sample, η' is the vector of parameter estimates from the gains function and δ is the vector of parameter estimates of the heteroskedasticity variables. For discrete models σ^2 is normalized (σ^2 =1).[3]

Data collection Overview: Primary and Secondary Data

Though the theory presented in Section 3 models the use of several technologies to avoid arsenic exposure, most people tend to switch from a red tubewell (>50 µg As/L) to a green tubewell (<50 µg As/L) or surface water. Existing data from an ongoing research initiative exploring health effects of arsenic exposure in Matlab are combined with primary data collected for this study. The Matlab area has seven sub-divisions (A through G) for major ongoing research activities. This analysis was performed on a stratified random sample of the population in Block A (Fig 4.1). High (>50 µg/L), medium (25 to <=50 µg/L) and low (<25 µg/L) levels of arsenic were used to stratify the sample population, where target respondent households were identified by the existing level of arsenic in the tubewell currently in use.[4] One thousand respondents were chosen per stratum.

The primary data consists of in-person interviews conducted in Matlab between March and June 2004 using survey questionnaires under the support of ICDDR,B. This analysis was performed on a stratified random sample of the population in Block A (Fig 4.1). High (>50 µg/L), medium (25 to <=50 µg/L) and low (<25 µg/L) levels of arsenic were used to stratify the sample population, where target respondent households were identified by the existing level of arsenic in the tubewell currently in use.[5] One thousand respondents were chosen per stratum. The total target sample size for the study was 3,000 households. Enumerators were able to complete interviews with 2,800 households. About 610 of the survey respondents could not be linked due to missing data in one or more of the secondary data sets so that the sample size reduced to 2,190 respondents. Each enumerator had access to the

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[3] Equations 19-22 were solved in SAS using the Qualitative and Limited Dependent Variable Model (QLIM) procedure, which analyzes univariate and multivariate limited dependent variable models.

[4] The arsenic levels are measured by field kit tests and subsequent laboratory tests carried out by ICDDR,B

family health card allocated to each household in Matlab.[6] The survey collected data on sociodemographic, health and safety characteristics as well as on household sources of drinking and cooking water, along with individuals' awareness of various issues related to arsenic. The survey was pre-tested by administering the instrument to forty people outside of the sample area. The secondary data consists of other sets of exogenous data from ICDDR,B including child health data on indicators (immunizations for diphtheria, tetanus, polio and measles as well as vitamin supplementation) as well as GIS data describing drinking water history per household.

Summary Statistics

In this system the collected data is utilized to specify four equations (Equations 19 to 22) with 12 variables. There are four endogenous variables and eleven exogenous variables. Table 1 reports dependent variable definitions, coding and descriptive statistics and includes corresponding notation from the empirical framework for clarity. Primary survey data provides the variables ProbHealthState (π_s), Gains (G_s) and ParentHealth (h_s^c) while secondary health data provides the variable ChildHealth (h_s^c).

The first dependent variable ProbHealthState is a binary variable that indexes an indicator for subjective probability of health state. It corresponds to a survey question that asks whether respondents believe whether their household will be in an ill state of health. If respondents believe their household will be in an ill state of health, ProbHealthState=1. Of the 2190 respondents, 744 (34%) respondents believed their household would be sick from exposure. The second dependent variable, Gains, represents the overall gains from mitigating arsenic exposure. Respondents were asked whether they thought expected gains from arsenic mitigation was high, moderate, low or none,

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[5] The arsenic levels are measured by field kit tests and subsequent laboratory tests carried out by ICDDR,B

6 A family health card has provisions to record detailed particulars of a family, including a unique identification number (RID) issued per household member, number of living children and immunization status, pregnancy

where 1 corresponds to no gains from mitigation and 4 corresponds to high gains from mitigation. Three hundred and ninety four respondents (18%) thought there were no gains, 131 respondents (6%) thought there were low gains, 1001 respondents (46%) thought there were moderate gains and 678 respondents (31%) expected high overall gains from arsenic mitigation.

The third dependent variable, ChildHealth is indicated by nutritional status of the child and is measured by the mid upper arm circumference of the child in millimeters. 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 points to severe malnutrition while a MUAC of less than 11 mm is considered acute malnutrition. MUAC is coded as one of four categories, 1 corresponding to acute malnutrition, 2 corresponding to severe malnutrition, 3 corresponding to malnourished while 4 corresponds to normal. One thousand two hundred and forty eight respondents (57%) had children with acute malnutrition, 832 respondents (38%) had children with severe malnutrition, 10 (0.46%) respondents had malnourished children and the remaining 109 respondents (5%) had children with normal nutritional status.

The fourth dependent variable, 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). 87 respondents (4%) reported very bad health, 832 respondents (38%) reported bad health, 810 respondents (37%) reported good health while the remaining 438 respondents (20%) reported very good health.

Tables 2 reports independent variable definitions, coding and descriptive statistics and includes corresponding notation from the empirical framework for clarity. Primary survey data provides the variables Avert (z_k), PriceAvert $(p_k z_k)$, TimeAvert (*w),* WorkMore (R_{WM}),

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status of women, record of services availed by pregnant women as well as occurrence of health complications and services availed by all members of a family at any service-delivery site. (ICDDR,B, 2003).

WorkAbility (R_{WA}), ParentRisk (r_m) and AGE and MALE (b_m) while secondary data provides the variables ChildRisk (r_c) and AAS ($\bar{r}$).

The first independent variable presented in Table 2, Avert, represents a switch away from a red tubewell to a safe drinking water source. Seven hundred and forty four respondents (34%) switched away from arsenic contaminated water. Survey data revealed the prevalent mitigation method in the sampled set of respondents is switching to a green tubewell. Note that this study may not capture all averting respondents, since the tubewell immediately adjacent to some respondents' homes is green and they do not need to switch. 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 zero, 100%, or part of the total cost. The mean initial cost is 178 Tk with a range from 0 to Tk. 7000. The independent variable TimeAvert reports the time spent averting for one trip to gather water and ranges from zero to 180 minutes while mean time spent averting is 44 minutes.

Other independent variables measure productivity gains from mitigating arsenic exposure in terms of ability to work due to mitigating arsenic exposure (WorkMore) and chances to work due to mitigating arsenic exposure (WorkAbility). Both WorkMore and WorkAbility are ordered categorical variables, where respondents rate their responses from 1 through 4, where 1 is corresponds to no chances or no increased ability to work, while 4 corresponds to a high increase in chances or ability to work. Five hundred and three respondents (23%) felt there were no increased chances, 153 respondents (7%) felt a low increase in chances, 898 respondents (41%) felt a moderate increase in chances, and the remaining 613 respondents (28%) felt a high increase in chances to work due to arsenic mitigation. Five hundred and three respondents (23%) felt there were no increased ability, 153 respondents (7%) felt a low increase in ability, 876 respondents (40%) felt a moderate increase in ability, and the remaining 635 respondents (29%) felt a high increase in ability to work due to arsenic mitigation.

The next variable, ChildRisk, acts as an indicator for perceived arsenic risk level for the child (r_c). ChildRisk is the recorded sum of vitamin A supplementations given to a child.[7] Vitamin A supplementations administered to children in the sample ranges from zero to ten supplementations, with three supplements given to children on average. Based on studies that posit a negative correlation between arsenic toxicity and vitamin A supplementations, and on advice parents are given to protect their child, the sum of Vitamin A 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). Perceived ambient risk level for the parent, ParentRisk (r_m), 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. Eight hundred and thirty two respondents (38%) were concerned about getting sick from arsenic contaminated water.

An objective ambient hazard level, AAS ($\bar{r}$) 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.[8] The anthropomorphic characteristics of the respondent are characterized by age and gender, corresponding to the independent variables AGE and MALE respectively where AGE is continuous and the average age of the respondent was 43 years old. MALE is binary, only 482 respondents (22%) were male – the target respondent was the female household head.

5. Results

Overall the model performance was stable; and consistent with convergence and directions of expected effects. At least 50% of the explanatory variables in each model was statistically significant

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[7] Vitamin A was reportedly administered either in capsule form for young adults or 100,000 IU for infants aged 6-11 months and 200,000 IU for children aged 12-59 twice a year.

[8] A simple hydride generation-atomic absorption spectrometry (HG-AAS) method for the determination of arsenic in the range of µg/L to mg/L concentrations in water was used (Wahed et al., 2006). The Bangladesh standard for the upper limit for arsenic exposure is 50 µg/L (McCarty, 2006). The U.S. EPA has set the arsenic standard for drinking water at 10 µg/L.

from zero at conventional levels. Table 3 presents expected signs of coefficient estimates, Table 4 presents coefficient estimates and Table 5 presents the heteroskedastically corrected model of marginal effects for coefficient estimates on probability of health state (ProbHealthState), the probability of high gains (Gains), good child health (ChildHealth) and good parent health (ParentHealth) respectively. Statistically significant results for coefficient estimates are discussed below.

Time spent averting (TimeAvert) increases the likelihood for respondents to report high gains from mitigation (Gains), for children to be in good nutritional health (ChildHealth) and for respondents to rate themselves in good health (ParentHealth). In addition, an increase in time spent averting decreases the perceived probability of ill health (ProbHealthState), so people believe that if they spend more time averting, they stave off the likelihood of being ill. People are also more likely to avert (Avert) and to take other protective actions (ChildRisk) such as taking children to the clinic for supplementations if children are in poor health (ChildHealth). Furthermore, people who travel to health clinics to take protective actions for their children through supplementations are more likely to perceive high gains from mitigation; (ChildRisk) increases the likelihood of high gains (Gains) from mitigating exposure. Similarly, perceived ambient risk for parent (ParentRisk) increases the likelihood of rating high gains (Gains) from mitigating exposure. Higher productivity gains from mitigation, WorkMore (more chances to work) and WorkAbility (high ability to work), increase the probability of high gains (Gains) from mitigating arsenic exposure. Overall, this likely suggests people perceive high health and work benefits from arsenic related mitigation activities.

The most compelling part of this story is despite the high premium individuals with high productivity may place time spent away from work, time spent averting is perceived to improve health and overall benefits from mitigation. Though time spent on walking to an arsenic free water source and on getting to health care services for children may take away time for other sustenance related activities in the household, parents place a still higher premium on their child’s health.

Welfare Effects

Relative valuation of child and parent health risk reduction is based on current health levels and is computed in terms of the significant marginal effects presented in the results table. The resulting ratio is interpreted as a change in willingness to pay for the decrease in perceived risk for a one-unit change in an explanatory variable. Computation of equation 14.1 using discrete rather than continuous changes shows that parents are willing to accept about a 2.6 percentage point increase in ambient arsenic risk level for themselves in return for lowering this risk to their children by one percentage point

$$\frac{-\frac{\nabla W}{\nabla r_c}}{-\frac{\nabla W}{\nabla r_m}} = 2.6$$

Parents' relative welfare effect of a marginal decrease in perceived risk level is evaluated at estimated opportunity cost of parent's time using local wage rates and mean time spent averting. However, here the issue is the value of lost time in terms of providing for survival (e.g. meals for sustenance) rather than gainful employment or leisure time. The estimated effect of the opportunity cost of time on gains from avoiding arsenic exposure $\overline{T}^{w}$ is evaluated at the mean of TimeAvert with an average daily wage rate of Tk. 75 for an unskilled worker in rural Bangladesh.[9] It is important to note the value for TimeAvert is based on one trip per day to gather water from a water source safe from arsenic contamination. The survey does not ask respondents for the number of trips per day. The parent's relative welfare effect of a marginal decrease in perceived risk level is approximately Tk.4.4 (US$0.06) (Equation 14.1 $MWTP^{m}_{r_c, r_m} = \frac{\psi_{r_c}}{\psi_{r_m}} \overline{T}^{w}$). This means that parents are willing to pay approximately 4 taka more per day for a one unit reduction in perceived risk level for their children than they are for themselves (assuming only one trip per day to gather water).

Discussion

The result showing parents value their child's health more than their own is corroborated by other studies linking child and parent health. Willingness to pay estimates from a study on parents valuation of latent health risks to their children show parents are willing to accept about a 2.5 percentage point increase in risk of skin cancer to themselves in return for lowering this risk to their children by one percentage point (Dickie and Gerking, 2003). Another study valuing health benefits of reducing environmental tobacco smoke exposure show smoking mothers on average value their child's health roughly 1.5-1.7 percentage points higher than their own health (Agee and Crocker, 2005). These relative estimates for respondent parent and child health in conjunction with other studies suggest that (*at risk)* parents value their child's health significantly higher than their own health (Dickie, 2004; Dockins, 2002). This study concludes that parents value their child's health 2.6 times as much as they value their own. The relative value revealed by this developing country application shows parents value their child's health more than their own whether they are in a highly resource constrained developing country or a relatively less resource constrained developed country.

This analysis suggests public health mitigation policies are working, but people avert at the expense of loss of valuable time away from work. Since increased work productivity from mitigation has a significant impact on expected 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.

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[9] The Bangladesh Bureau of Statistics (2004) reports an average wage rate of Tk.75 per day for an unskilled rural worker in Matlab (US$1.08, at 2007 exchange rate of Tk.69.4 to US$1)

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APPENDIX
Derivation of First Order Conditions

Households choose from a finite set of K mitigating activities. Mitigating arsenic exposure is defined in terms of effectiveness $x_k(z_k)$ and intensity z_k of activities.

$$\alpha_k = x_k(z_k)z_k \tag{3.1.1}$$

$\pi_s(\alpha_k, r_c, r_m, \bar{r}, w)$ is the households joint density function for the two random variables $\pi_s^c(\alpha_k, r_c, \bar{r}, w)$ and $\pi_s^m(\alpha_k, r_m, \bar{r}, w)$ so that:

$$\pi_s(\alpha_k, r_c, r_m, \bar{r}, w) = \text{Prob}(\pi_s^c(.), \pi_s^m(.)) = \sum_{\pi_s^c}\sum_{\pi_s^m} \pi_s(\pi_s^c(\alpha_k, r_c, \bar{r}, w), \pi_s^m(\alpha_k, r_m, \bar{r}, w)) \tag{3.1.2}$$

Parents choose z_k to maximize expected utility:

$$\underset{z_k}{Max} EU = \sum_s [\pi_s(\alpha_k, r_c, r_m, \bar{r}, w) U_s\{W_0 - p_k z_k + G_s(\alpha_k, r_c, r_m, \bar{r}, w), h_s^c(\alpha_k, r_c, r_m, \bar{r}, b_c), h_s^m(\alpha_k, r_c, r_m, \bar{r}, b_m)\}]$$

where

$$\pi_s = \pi_s(\alpha_k, r_c, r_m, \bar{r}, w) \tag{3.1.3}$$

$$W = W_0 + G_s(\alpha_k, r_c, r_m, \bar{r}, w) - p_k z_k \tag{3.1.4}$$

$$G_s = G_s(\alpha_k, r_c, r_m, \bar{r}, w) \tag{3.1.5}$$

$$h_s^c = h_s^c(\alpha_k, r_c, r_m, \bar{r}, b_c) \tag{3.1.6}$$

$$h_s^m = h_s^m(\alpha_k, r_c, r_m, \bar{r}, b_m) \tag{3.1.7}$$

Efficiency Condition (F.O.C. from maximizing the objective function w.r.t. z_k)

$$\frac{1}{E\lambda}\left[\sum_s \frac{\partial \Pi_s}{\partial \alpha_k} U_s(x_k'(z_k)(z_k)+x(z_k))+\sum_s \Pi_s \frac{\partial U_s}{\partial W}\frac{\partial G_s}{\partial \alpha_k}(x_k'(z_k)(z_k)+x(z_k))+\sum_s \Pi_s \frac{\partial U_s}{\partial h_s^c}\frac{\partial h_s^c}{\partial \alpha_k}(x_k'(z_k)(z_k)+x(z_k))+\sum_s \Pi_s \frac{\partial U_s}{\partial h_s^m}\frac{\partial h_s^m}{\partial \alpha_k}(x_k'(z_k)(z_k)+x(z_k))\right]=p_k \tag{3.1.8}$$

where

$$\frac{1}{E\lambda}=\sum_s \Pi_s \frac{\partial U_s}{\partial W} \tag{3.1.9}$$ [10]

The efficiency condition can be rewritten with the alpha partial derivatives represented by the γ_α vectors, and the unobservable utility terms represented by the ξ vectors:

$$\gamma_\alpha^1 \xi^1+\gamma_\alpha^2 \xi^2+\gamma_\alpha^3 \xi^3+\gamma_\alpha^4 \xi^4 = p_k \tag{3.1.10}$$

$$\left[\gamma_\alpha{}^1 \gamma_\alpha{}^2 \gamma_\alpha{}^3 \gamma_\alpha{}^4\right] \underbrace{\begin{bmatrix} \xi^1 \\ \xi^2 \\ \xi^3 \\ \xi^4 \end{bmatrix}}_{Utility_{Terms}} = p_k \tag{3.1.11}$$

where $\gamma_\alpha{}^1$ = Effect of mitigating arsenic exposure on health probability.
$\gamma_\alpha{}^2$ = Effect of mitigating arsenic exposure on gains.
$\gamma_\alpha{}^3$ =Effect of mitigating arsenic exposure on child health.
$\gamma_\alpha{}^4$ = Effect of mitigating arsenic exposure on parent health.

Marginal WTP for child protection (F.O.C. from maximizing the objective function with respect to r_c , and solving for that change in mitigating arsenic exposure α_k which holds utility constant)

$$\sum_s \frac{\partial \Pi_s}{\partial r_c} U_s + \Pi_s (\frac{\partial U_s}{\partial W}\frac{\partial W}{\partial r_c}+\frac{\partial U_s}{\partial W}\frac{\partial G_s}{\partial r_c}+\frac{\partial U_s}{\partial h_s^c}\frac{\partial h_s^c}{\partial r_c}+\frac{\partial U_s}{\partial h_s^m}\frac{\partial h_s^m}{\partial r_c}=0 \tag{3.1.12}$$

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[10] $\frac{1}{E\lambda}$ is the expected marginal utility of income.

$$-\frac{\partial W}{\partial r_c} = \left[\frac{\partial \Pi_1}{\partial r_c} \cdots \frac{\partial \Pi_s}{\partial r_c}\right] \begin{bmatrix} \frac{U_1}{E\lambda} \\ \vdots \\ \frac{U_s}{E\lambda} \end{bmatrix} + \left[\frac{\partial G_1}{\partial r_c} \cdots \frac{\partial G_s}{\partial r_c}\right] \begin{bmatrix} \frac{\Pi_1 \frac{\partial U_1}{\partial W}}{E\lambda} \\ \vdots \\ \frac{\Pi_s \frac{\partial U_s}{\partial W}}{E\lambda} \end{bmatrix} + \left[\frac{\partial h_1^c}{\partial r_c} \ldots\ldots \frac{\partial h_s^c}{\partial r_c}\right] \begin{bmatrix} \frac{\Pi_1 \frac{\partial U_1}{\partial h_1^c}}{E\lambda} \\ \vdots \\ \frac{\Pi_s \frac{\partial U_s}{\partial h_s^c}}{E\lambda} \end{bmatrix} + \left[\frac{\partial h_1^m}{\partial r_c} \ldots\ldots \frac{\partial h_s^m}{\partial r_c}\right] \begin{bmatrix} \frac{\Pi_1 \frac{\partial U_1}{\partial h_1^m}}{E\lambda} \\ \vdots \\ \frac{\Pi_s \frac{\partial U_s}{\partial h_s^m}}{E\lambda} \end{bmatrix} \tag{3.1.13}$$

$$-\frac{\partial W}{\partial r_c} = \gamma_{r_c}{}^{\pi}\xi^1 + \gamma_{r_c}{}^{G}\xi^2 + \gamma_{r_c}{}^{c}\xi^3 + \gamma_{r_c}{}^{m}\xi^4 \tag{3.1.14}$$

$$-\frac{\partial W}{\partial r_c} = \left[\gamma_{r_c}{}^{\pi} + \gamma_{r_c}{}^{G} + \gamma_{r_c}{}^{c} + \gamma_{r_c}{}^{m}\right] \underbrace{\begin{bmatrix} \xi^1 \\ \xi^2 \\ \xi^3 \\ \xi^4 \end{bmatrix}}_{Utility_{terms}} \tag{3.1.15}$$

where $\gamma_{r_c}{}^{\pi}$ = Effect of child’s perceived ambient risk level on health probability.

$\gamma_{r_c}{}^{G}$ = Effect of child’s perceived ambient risk level on gains from mitigation.

$\gamma_{r_c}{}^{c}$ = Effect of child’s perceived ambient risk level on own health.

$\gamma_{r_m}{}^{m}$ = Effect of parents perceived ambient risk on child health.

Marginal WTP for self protection (F.O.C. from maximizing the objective function with respect to r_m, and solving for that change in mitigating arsenic exposure α_k which holds utility constant):

$$-\frac{\partial W}{\partial r_m} = \left[\frac{\partial \Pi_1}{\partial r_m} \cdots \frac{\partial \Pi_s}{\partial r_m}\right] \begin{bmatrix} \frac{U_1}{E\lambda} \\ \vdots \\ \frac{U_s}{E\lambda} \end{bmatrix} + \left[\frac{\partial G_1}{\partial r_m} \cdots \frac{\partial G_s}{\partial r_m}\right] \begin{bmatrix} \frac{\Pi_1 \frac{\partial U_1}{\partial W}}{E\lambda} \\ \vdots \\ \frac{\Pi_s \frac{\partial U_s}{\partial W}}{E\lambda} \end{bmatrix} + \left[\frac{\partial h_1^c}{\partial r_m} \ldots\ldots \frac{\partial h_s^c}{\partial r_m}\right] \begin{bmatrix} \frac{\Pi_1 \frac{\partial U_1}{\partial h_1^c}}{E\lambda} \\ \vdots \\ \frac{\Pi_s \frac{\partial U_s}{\partial h_s^c}}{E\lambda} \end{bmatrix} + \left[\frac{\partial h_1^m}{\partial r_m} \ldots\ldots \frac{\partial h_s^m}{\partial r_m}\right] \begin{bmatrix} \frac{\Pi_1 \frac{\partial U_1}{\partial h_1^m}}{E\lambda} \\ \vdots \\ \frac{\Pi_s \frac{\partial U_s}{\partial h_s^m}}{E\lambda} \end{bmatrix} \tag{3.1.16}$$

$$-\frac{\partial W}{\partial r_m} = \left[\gamma_{r_m}{}^{1}\xi^1 + \gamma_{r_m}{}^{2}\xi^2 + \gamma_{r_m}{}^{3}\xi^3 + \gamma_{r_m}{}^{4}\xi^4\right] \tag{3.1.17}$$

$$-\frac{\partial W}{\partial r_m}=\left[\gamma_{r_m}{}^{\pi}+\gamma_{r_m}{}^{G}+\gamma_{r_m}{}^{c}+\gamma_{r_m}{}^{m}\right]\underbrace{\begin{bmatrix}\xi^1\\ \xi^2\\ \xi^3\\ \xi^4\end{bmatrix}}_{Utility_{terms}} \qquad (3.1.18)$$

where $\gamma_{r_m}{}^{\pi}$ = Effect of parents perceived ambient risk level on health probability.

$\gamma_{r_m}{}^{G}$ = Effect of parents perceived ambient risk level on gains from mitigation.

$\gamma_{r_m}{}^{c}$ = Effect of parents perceived ambient risk level on child health.

$\gamma_{r_m}{}^{m}$ = Effect of parents perceived ambient risk level on own health.

Equations 3.1.15 and 3.1.18 contain observable and unobservable utility terms. The column vectors contain the unobservable utility terms. In order to recover marginal willingness to pays without unobservable utility terms, the efficiency condition (equation 3.1.8) can be used by arranging the α partial derivatives into a vector ψ_α, and the unobservable utility terms into a vector Z.

$$\left[\gamma_\alpha{}^1\gamma_\alpha{}^2\gamma_\alpha{}^3\gamma_\alpha{}^4\right]=\psi_\alpha \qquad (3.1.19)$$

$$\underbrace{\begin{bmatrix}\xi^1\\ \xi^2\\ \xi^3\\ \xi^4\end{bmatrix}}_{Utility_{Terms}} = Z \qquad (3.1.20)$$

Equation 3.1.11 can then be rewritten in terms of Z and ψ_α

$$\psi_\alpha Z = p_k \qquad (3.1.21)$$

Solving for Z:

$$Z = \psi_\alpha{}^{-1} p_k \qquad (3.1.22)$$

Repeating equation 3.1.15 and 3.1.18 for ease of exposition:

$$-\frac{\partial W}{\partial r_c}=\left[\gamma_{r_c}{}^{\pi}+\gamma_{r_c}{}^{G}+\gamma_{r_c}{}^{c}+\gamma_{r_c}{}^{m}\right]\underbrace{\begin{bmatrix}\xi^1\\ \xi^2\\ \xi^3\\ \xi^4\end{bmatrix}}_{Utility_{terms}} \qquad (3.1.15)$$

$$-\frac{\partial W}{\partial r_m} = \left[\gamma_{r_m}{}^{\pi} + \gamma_{r_m}{}^{G} + \gamma_{r_m}{}^{c} + \gamma_{r_m}{}^{m}\right] \underbrace{\begin{bmatrix} \xi^1 \\ \xi^2 \\ \xi^3 \\ \xi^4 \end{bmatrix}}_{Utility_{terms}} \tag{3.1.18}$$

Arranging the r_c partial derivatives into a vector ψ_{r_c} and the r_m partial derivatives into a vector ψ_{r_m} :

$$\left[\gamma_{r_c}{}^{\pi} + \gamma_{r_c}{}^{G} + \gamma_{r_c}{}^{c} + \gamma_{r_c}{}^{m}\right] = \psi_{r_c} \tag{3.1.23}$$

$$\left[\gamma_{r_m}{}^{\pi} + \gamma_{r_m}{}^{G} + \gamma_{r_m}{}^{c} + \gamma_{r_m}{}^{m}\right] = \psi_{r_m} \tag{3.1.24}$$

Now rewriting equations 3.1.15 and 3.1.18 in terms of ψ_{r_c} , ψ_{r_m} using expressions 3.1.23 and 3.1.24 and substituting the expression for Z from equation 3.1.22

$$-\frac{\partial W}{\partial r_c} = \psi_{r_c} Z \tag{3.1.25}$$

$$-\frac{\partial W}{\partial r_c} = \psi_{r_c} \psi_{\alpha}^{-1} p_k \tag{3.1.26}$$

$$-\frac{\partial W}{\partial r_m} = \psi_{r_m} Z \tag{3.1.27}$$

$$-\frac{\partial W}{\partial r_m} = \psi_{r_m} \psi_{\alpha}^{-1} p_k \tag{3.1.28}$$

The relative valuation of child and parent health is equal to the ratio of equation 3.1.26 over 3.1.28:

$$\frac{-\frac{\partial W}{\partial r_c}}{-\frac{\partial W}{\partial r_m}} = \frac{\psi_{r_c} \psi_{\alpha}^{-1} p_k}{\psi_{r_m} \psi_{\alpha}^{-1} p_k} \tag{3.1.29}$$

$$\frac{-\frac{\partial W}{\partial r_c}}{-\frac{\partial W}{\partial r_m}} = \frac{\psi_{r_c}}{\psi_{r_m}} = \frac{\left[\gamma_{r_c}{}^{\pi} + \gamma_{r_c}{}^{G} + \gamma_{r_c}{}^{c} + \gamma_{r_c}{}^{m}\right]}{\left[\gamma_{r_m}{}^{\pi} + \gamma_{r_m}{}^{G} + \gamma_{r_m}{}^{c} + \gamma_{r_m}{}^{m}\right]} \tag{3.1.30}$$

Fig. 1 Tubewell Distribution in Study Area (Block-A) in Matlab

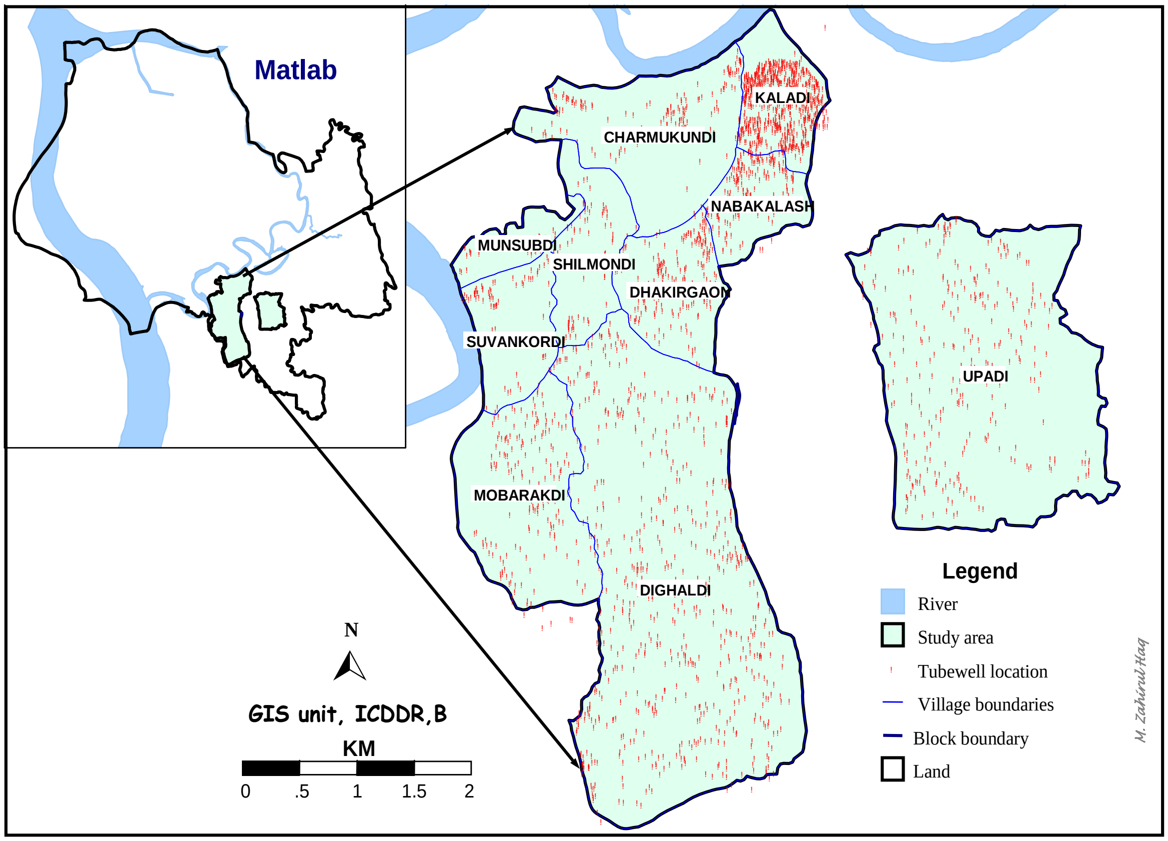

Table 1. Dependent Variables and Descriptive Statistics (n=2,190)

Variable (Notation)	**Definitions**	**Descriptive Statistics**
ProbHealthState (π_s)	Perception of whether household members will be in an ill health state or well health state	34% = 1
	1 = Ill	
	0 = Well	
Gains (G_s)	Gains from mitigating	
	1 = No gains from mitigating	18%
	2 = Little gains from mitigating	6%
	3 = Moderate gains from mitigating	46%
	4 = High gains from mitigating	31%
ChildHealth (h_s^c)	Poor health is indicated by nutritional status based on mid-upper arm circumference (divided by age)	
	1, <=11 mm = Acute Malnutrition	57%
	2, 11mm - 125 mm = Severe Malnutrition	38%
	3, 125 - 134 mm = Malnourished	0.46%
	4, > 134 mm = Normal	5%
ParentHealth (h_s^c)	Subjective measure of own health	
	1 = Very bad health	4%
	2 = Bad health	38%
	3 = Good health	37%
	4 = Very good health	20%

Table 2 Independent Variables and Descriptive Statistics (n=2,190)

Variable (Notation)	Definitions	Descriptive Statistics
Avert (z_k)	Switched to water source safe from arsenic contamination. 1=Yes 0=No	34%=Yes
PriceAvert ($p_k z_k$)	Cost of averting in Taka.	Mean = 178
	Range	0 Tk – 7000 Tk
TimeAvert (w)	Walking time to water source safe from arsenic contamination.	Mean = 44
	Range	0 to 180 minutes
WorkMore (R_{WM})	Subjective rating of own chances to work due to mitigating arsenic exposure.	
	1 = No increased chances to work	23%
	2 = Little increased chances to work	7%
	3 = Moderate increase in chances to work	41%
	4 = High increase in chances to work	28%
WorkAbility (R_{WA})	Subjective rating of own ability to work due to mitigating arsenic exposure.	
	1 = No increased ability	23%
	2 = Little increased ability	7%
	3 = Moderate increase in ability	40%
	4 = High increase in ability	29%
ChildRisk (r_c)	Sum of vitamin A supplementations provided.	Mean = 3
	Range	0 – 10 doses
ParentRisk (r_m)	Parents perception if there is risk of arsenic problems in drinking water. 1 = No 0 = Yes	62%=No
AAS ($\bar{r}$)	Arsenic level	Mean = 227 µg As/L
	Range	1 – 1019 µg As/L
AGE (ρ_m)	Age of respondent	Mean = 43
	Range	14 – 106 Years
MALE (ρ_m)	Sex of respondent 1 = Male 0 = Female	22% = 1

Table 3. Expected Signs of Explanatory Variable Coefficients

Variable (Notation)	Gains	ProbHealthState	ChildHealth	ParentHealth
Avert	+	-	?	?
Gains		-	+	+
PriceAvert	-	+		
TimeAvert	+	-	+	+
WorkMore	+			
WorkAbility	+			
ChildRisk	+	-	?	?
ParentRisk	+	-	?	?
AAS	+	+	-	-
AGE				-
MALE				?

Table 4. Coefficient Estimates (n = 2,190)

VARIABLE NAMES	Gains	ProbHealthState	ChildHealth	ParentHealth
Avert	-0.1361***[a] (0.0456)[b]	0.0215 (0.0666)	-0.1673*** (0.0577)	-0.0280 (0.0438)
Gains		-0.1377*** (0.02006)	0.0126 (0.0355)	0.0589** (0.0307)
PriceAvert	0.00005 (0.00003)	0.00008* (0.00004)		
TimeAvert	0.0023*** (0.0005)	-0.0012* (0.0007)	0.0013** (0.0006)	0.0014*** (0.0006)
WorkMore	0.3720*** (0.0417)			
WorkAbility	0.3269*** (0.0376)			
ChildRisk	0.0134** (0.0062)	0.0043 (0.0093)	-0.0366*** (0.0086)	-0.0084 (0.0081)
ParentRisk	0.0140*** (0.0015)	-0.0093 (0.0103)	0.0070 (0.0116)	0.0053 (0.0086)
AAS	0.00008 (0.00009)	0.0004*** (0.0002)	0.00018 (0.0001)	-0.0003*** (0.0001)
AGE				-0.0177*** (0.0017)
MALE				-0.0080 (0.0116)
Log Likelihood	-7670			
AIC	15441			

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

[b] Standard errors are in parentheses.

Table 5 Marginal Effects

VARIABLE NAMES	Marginal Effect Gains	Discrete Change ProbHealthState	Marginal Effect ChildHealth	Marginal Effect ParentHealth
Avert	-0.05	0.01	-0.08	-0.003
Gains		-0.06	0.006	0.07
PriceAvert	0.00002	0.00003		
TimeAvert	0.0009	-0.0005	0.0006	0.002
WorkMore	0.14			
WorkAbility	0.12			
ChildRisk	0.005	0.002	-0.018	-0.009
ParentRisk	0.005	-0.005	0.003	0.006
AAS	0.00003	0.0002	0.00009	-0.0003
AGE				-0.002
MALE				-0.0009

[11]

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[11] The 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).