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ARSENIC MITIGATION IN BANGLADESH: A HOUSEHOLD LABOR MARKET APPROACH

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A major environmental tragedy of modern times is the widespread arsenic contamination of shallow drinking water wells in rural Bangladesh, which went unrecognized for years. Large numbers of people are now starting to show a range of symptoms long associated with chronic arsenic exposure. Rural families in Bangladesh, one of the poorest countries in the world, face financial risks from major illness both from the cost of medical care and from the loss of income associated with reduced labor supply and productivity. Because of the lack of comprehensive government assistance programs and formal insurance markets, most of these households have to rely on private, informal, insurance mechanisms. For the poor these typically take place at the household level. While arsenic-related health problems in Bangladesh have long received considerable attention (e.g., Smith, Lingas, and Rahman 2000), implications for the labor supply have not been examined. In this article, we look at the impacts of arsenic contamination on both the overall level of hours worked and the distribution of these hours within households. Using a large sample of rural households matched to arsenic exposure, we find that (*a*) overall household labor supply is 8% smaller due to arsenic exposure and (*b*) intrahousehold reallocation of work between males and females is used to self-insure against the risk induced by arsenic exposure.

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The Arsenic Problem in Bangladesh

Until about 30 years ago, Bangladesh households relied almost exclusively on surface water for drinking purposes. That source, however, contained waterborne pathogens causing life-threatening diseases that would have required expensive and complicated treatments to render it safe. Encouraged by international aid agencies, millions of tube wells were installed throughout the country, making groundwater resources the main source of drinking water.

Chronic arsenic poisoning attributed to groundwater ingestion was first diagnosed in Bangladesh in 1993. Direct confirmation that an enormous number of tube wells were contaminated by arsenic came when the British Geological Survey and the Department of Public Health Engineering of Bangladesh (2001) carried out a survey of 3,500 tube wells from sixty-one out of sixty-four districts of Bangladesh between 1998 and 1999. The results show that 27% of the tube wells less than 150 m deep exceeded the Bangladesh standard for arsenic in drinking water of 50 μg/L. Using the World Health Organization (WHO) guideline value of 10 μg/L as the reference level, the figure rises to 46%. It is now believed that around 35 million people are exposed to an arsenic concentration in drinking water exceeding 50 μg/L, while 57 million people are exposed to concentration levels exceeding 10 μg/L.

Chronic exposure to arsenic in drinking water has often been associated with the development of skin cancers and internal cancers, especially of the bladder, liver, and lungs, and a wide variety of other health conditions, such as diabetes, respiratory problems, cardiovascular diseases, hyperpigmentation, hypopigmentation, and keratosis, a condition in which painful nodules grow on the palms of

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the hands and soles of the feet (Chowdhury et al. 2000). The latency period for arsenic-linked cancers is estimated to be approximately twenty years, and depending on concentrations, the time delay from first exposure to the manifestation of arsenic-related skin disorders is about ten years. The initial effects of chronic arsenic exposure are a feeling of general lethargy coupled with mild headaches and confusion, effects that are likely to impact labor supply but not necessarily show up as a reported health condition in surveys.

Economic View of the Problem

Most of the economic work on arsenic contamination in Bangladesh has had an epidemiological focus that has tried to effectively monetize a dose response relation using either a cost of illness or a willingness to pay approach (e.g., Ahmad, Goldar, and Misra 2005). Not all of the costs of ill health, however, are borne by the individual whose health is temporarily or permanently impaired. This is particularly true in places like rural Bangladesh, where there is no formal insurance system and government-provided health care is minimal.

In a seminal paper, Pitt and Rosenzweig (1990) demonstrate the difficulties of identifying both the own and cross effects of health within a household. In particular, they develop and implement a method for estimating the effects of infant health on the differential allocation of time by other family members that is consistent with models of household behavior. A more recent, but related, literature has focused on the impact of health problems on household labor allocation, mostly in the context of AIDS in Africa (e.g., d'Adda et al. 2009; Graff-Zivin, Thirumurthy, and Goldstein 2009). The main findings from this literature are that AIDS treatment results in significant intrahousehold reallocation of time and has both direct impacts on patients and indirect impacts on their households, which is consistent with the findings of the older literature on time allocation patterns associated with idiosyncratic health and income shocks in rural settings (e.g., Pitt, Rosenzweig, and Hassan 1990). Surprisingly, to our knowledge, arsenic contamination in Bangladesh has never been considered in this context.

In addition to changes in household labor supply, holding of assets has also been advanced as a path through which households help to insure consumption against major illness. Overall, the findings from these studies indicate that families with low income or few assets are less able to insure consumption against income shocks (e.g., Gertler and Gruber 2002; Jalan and Ravallion 1999). While we control for household assets, they may play less of an insurance role with respect to chronic disease conditions than they do with respect to either acute health problems or adverse production shocks such as those due to weather.

Econometric Issues

Identification Strategy

Empirical estimates of the economic consequences of changes in health conditions have long been known to be biased by simultaneity of health and earnings, errors in measurements, and omitted variables (e.g., Thomas and Strauss 1997). Health may affect the productivity of the worker (and hence labor choices, as well as the labor choices of household members), but productivity provides the resources to invest in better nutrition and health care, and hence to produce better health (which in turn affects labor choices, productivity, and wages). Measurement error in the self-reporting of health status is also thought to be a serious source of parameter bias, and determining exactly what variables cause a health problem is difficult. The way around these problems, given our interest in labor supply impacts, is to find an instrument that is correlated with the predictor of interest—health effects related to arsenic—but uncorrelated with the error term. The error term effectively includes unobserved health endowments; preferences for health; and regional factors related to the availability of health care, employment opportunities, and credit. This is a tall order for any instrument to meet, but arsenic contamination in Bangladesh, unfortunate as it is, has the properties of an ideal instrument for identification of the health effects on labor supply.

The desirable properties of arsenic concentration levels as an instrument follow from: (*a*) households being unaware of it (with a long latency), (*b*) household mobility being quite low, (*c*) effectively having no other real choice for (nonbiologically contaminated) water than using a tube well over the relevant time period, and (*d*) being a widely spread, highly variable deep geological feature unlikely to be correlated with other physical features related to health status. There are two potential problems with the arsenic concentration variable we have available. First, the measure we use is average arsenic levels at the level of the *thana*, a small administrative unit associated with a police station. There is some variability both spatially and temporally within a *thana,* which leads to the usual measurement error with the relevant coefficients tending to be biased toward zero. Our identification strategy effectively relies on the cross-*thana* variation strongly dominating within the *thana* variation, which appears to be the case. Second, while there is a reasonable amount of variation in arsenic within higher-level political jurisdictions, there are also systematic differences, since arsenic contamination is generally much worse in the regions near the Bay of Bengal. Our analysis, which should be thought of as an initial effort at modeling arsenic-induced labor supply impacts, ignores possible measurement error bias and the possibility (conditional on observed covariates) that arsenic contamination levels somehow proxy for a complex geographic pattern of proclivity toward working unrelated to arsenic.

Reliably identifying specific health effects on individual household members in the dataset available is difficult because of reporting issues, the large fraction of missing data, and more specifically the reasonably large number of diseases associated with chronic arsenic poisoning, many of which can have other causes. Because we are most interested in the impact of arsenic contamination on household labor supply, we move directly to a reduced form equation with the level of arsenic contamination as the exogenous variable. We have reliable information on the total number of labor hours supplied by each household, but it is clear that there are substitution possibilities within households that may be important, so we aggregate hours worked to the household level and then control for household composition. This allows us to test whether exposure to different arsenic levels influences both the overall level of hours worked and the implicit distribution of these hours within a household.

Specification of the labor supply model

We estimate a labor supply model in which the sum of hours worked by all members in the *i*th household (HHW_i) over the year is assumed to depend on the household demographic composition, which is operationalized as the number of males and females in different age bands [0–5 years, 5–10, 10–15, 15–25, 25–45, 45–55, 55–65, 65+].[1] We control for a number of other household characteristics by including an indicator variable for the household's religion (1 for Islam and 0 otherwise), the age of the reported head of the household (typically the oldest male), and the maximum education level of any household members and for the sizable fraction of the sample who did not report an education level (which, from other indicator variables, appears to be low), as well as for two continuous asset related variables: the households' overall wealth and the the quantity of cultivable land owned. The base model employs squared versions of these variables, and the most comprehensive model includes interactions with the arsenic exposure level.

A household's labor supply choices can be affected by the health of its members. Health is unobserved, but we will use the average arsenic level as measured in the *thana*. The average arsenic level can impact labor supply directly as well as indirectly through its cross effects with household characteristics. A simple version of the labor supply model can be written as:

$$HHW_i = \alpha X_i + \beta AS_i + \theta X_i AS_i + \mu_i \quad (1)$$

where X_i represents the household's characteristics (e.g., household demographic composition by sex and age groups), AS_i is the average level of arsenic contamination in the *thana* where the household is located, and μ_i is the error term.

We are interested in three issues. First, is arsenic contamination detrimental to household health in the sense of a direct negative effect on work hours? Second, is this effect linear or does the model in equation (1) need to be modified to allow arsenic to enter in as a logarithmic transformation or by using a quadratic specification? Third, are there significant interactions between the level of arsenic contamination and (*a*) the indicators of household composition, (*b*) other demographic variables, and (*c*) asset indicators. If so, we expect some parameters of the θ vector to be significant. Cross effects between AS and household demographic characteristics would suggest that households are not completely insured against the adverse effects of arsenic contamination, while significant coefficients on asset variables would suggest some type of compensatory effects via this mechanism.

[1] The hours-worked variable includes wage employment and self-employment in nonagricultural and agricultural sectors for in-kind remuneration, including working on household land plots.

Cox Proportional Hazards Model

A major issue with equation (1) is the assumption to be made about μ_i. Normality would appear to be a bad assumption because it allows for the possibility of working negative hours, and there is a finite upper bound on how many hours a person can work in a year. The combination of these two considerations suggests using a survival modeling framework that enforces nonnegativity and typically assumes a finite upper bound support. One can fit either a parametric survival specification like the Weibull or a semiparametric specification like the Cox proportional hazard model. Because we do not have much of a feel for what the baseline survival distribution for *HHW* (conditional on covariates) should look like and because our primary interest is in how arsenic shifts this survival distribution, the Cox proportional hazard model specification, which allows for an arbitrary baseline distribution and allows covariates to proportionately shift the baseline hazard function $h_0(\bullet)$, would appear to be the natural choice.[2] The basic form of the Cox model for our situation is:

$$(2) \qquad h(HHW_i \mid X_i, AS_i) = h_0(HHW)\exp(\alpha AS_i + \beta X_i).$$

The coefficients from this model can be expressed in different ways, but the most popular is in terms of the hazard rate. Coefficients on a covariate larger than 1 indicate that the dependent variable gets smaller (i.e., household labor hours shrink) relative to the baseline hazard, while coefficients between 0 and 1 (which are negative in the untransformed specification) indicate that the dependent variable gets larger (i.e., labor hours increase) relative to the baseline. For an indicator variable, the interpretation is straightforward: a coefficient of 1.5 indicates that an observation for which the indicator is 1 dies off 50% faster than if the indicator were zero. For sizable changes in a continuous predictor, small deviations in its coefficient from the baseline hazard of 1 can result in large predicted differences in the number of household hours worked.

[2] Recall that if $f(t)$ is the density and $F(t)$ the cumulative distribution function, then the survival function is $1 - F(t)$ and the hazard function is $f(t)/S(t)$. $F(t)$ and $S(t)$ are easily expressed in terms of the integrated hazard rate.

Data

Our sample comprises 4,259 rural Bangladesh households from the Household Income and Expenditure Survey (HIES) carried out by the Bangladesh Bureau of Statistics (BBS) in 2000 that could be matched with data on arsenic contamination from a large-scale study done between March 1998 and December 1999 by the British Geological Survey (BGS).[3] These households belong to 220 different *thanas* (each has 20 randomly sampled households), for which we have information on the average arsenic tube well concentration. On average, our sample households worked 3,650 hours per year, which represents 747 hours per capita per year. The average concentration of arsenic is 62 µg/L, which is above both the WHO and Bangladesh standards of 10 and 50 µg/L, respectively. Arsenic exposure levels varied from a low of 0.3 µg/L to a high of 421 µg/L (descriptive statistics are available upon request). Our arsenic variable is scaled in 10-µg/L units, which can be thought of as multiples of the WHO standard.

Estimation Results

Estimation results from different Cox proportional hazard models using Efron's approach to ties are provided in table 1. There are three models.[4] The baseline model 1 does not contain the arsenic level variable. Model 2 adds the arsenic variable in its linear and quadratic form. Model 3 adds interaction terms between arsenic and some of the demographic variables in model 1.

Model 1 shows very significant deviations from the baseline hazard function for hours

[3] Since arsenic contamination has not been measured in all *thanas* covered by the HIES, households without BGS data were dropped. The BGS survey design suggests that this should not create sample selection effects. We have also dropped households that do not rely on tube wells (which represent 4.5% of the original sample), since we do not have an indicator of their arsenic exposure levels. A similar analysis conducted for urban households found little effect on labor supply due to arsenic. This lends some additional credibility to the results reported here, as urban arsenic levels are generally much lower and have less variability due to the use of deeper wells.

[4] We have 161 households that worked no hours. These observations are coded as having worked one hour, which is smaller than the smallest positive number of hours recorded in the dataset, which is two hours. An advantage of the Cox proportional hazards models is that its results are invariant to exactly how these censored observations are coded as long as it is less than the smallest observed positive value. A simple probit model with a subset of the covariates in model 1 shows that AS is a significant predictor ($p < 0.001$) of working zero hours.

Table 1. Results from Cox Proportional Hazard Models

Variable	Model 1	z-Statistic	Model 2	z-Statistic	Model 3	z-Statistic
Female 0–5 years	1.0116	0.45	1.0048	0.18	1.0192	0.73
6–10	0.9067	−3.72	0.9073	−3.70	0.8544	−4.54
11–15	0.9465	−1.86	0.9394	−2.11	0.9616	−1.10
16–25	0.7834	−2.62	0.7877	−2.56	0.7946	−2.41
26–45	1.1312	1.19	1.1093	1.00	1.1410	1.19
46–55	1.0039	0.03	1.0008	0.01	0.8864	−0.79
56–65	1.0170	0.32	1.0093	0.18	0.9380	−0.97
65+	0.9754	−0.39	0.9585	−0.67	0.8790	−1.61
Male 0–5 years	1.0008	0.03	0.9899	−0.39	1.0072	0.27
6–10	0.8755	−5.07	0.8779	−4.96	0.8489	−5.18
11–15	0.6903	−12.86	0.6885	−12.95	0.6786	−11.16
16–25	0.5255	−24.08	0.5212	−24.40	0.5350	−19.31
26–45	0.5157	−17.76	0.5083	−18.14	0.5988	−11.20
46–55	0.5239	−11.24	0.5201	−11.38	0.5743	−7.89
56–65	0.6356	−6.40	0.6271	−6.58	0.7111	−3.96
65+	0.6906	−4.11	0.6825	−4.22	0.6492	−3.97
Islam	1.6374	4.01	1.6516	4.09	1.6927	4.24
Islam*F16–25	1.0023	0.02	0.9987	−0.01	0.9431	−0.61
Islam*F26–45	0.7207	−3.00	0.7327	−2.85	0.7063	−3.14
Islam*F46–55	0.7856	−1.61	0.7861	−1.61	0.8122	−1.37
Age (head)	0.9901	−1.17	0.9889	−1.30	0.9914	−0.99
Age^2	1.0001	1.23	1.0001	1.31	1.0001	1.45
MaxED	1.0270	3.73	1.0274	3.78	1.0086	0.98
MissMaxED	1.1983	3.04	1.1985	3.04	1.1081	1.42
Acres	1.0814	7.45	1.0843	7.76	1.0987	7.60
$Acres^2$	0.9994	−4.44	0.9993	−4.54	0.9993	−4.94
Assets	0.9556	−2.85	0.9560	−2.82	0.9439	−3.29
$Assets^2$	1.0000	1.47	1.0000	1.48	1.0000	2.02
Arsenic			1.0226	4.59	1.0448	3.57
$Arsenic^2$			0.9996	−2.50	0.9996	−2.52
AS*(household size <3)					1.0261	4.11
AS*F6–10					1.0074	2.59
AS*F11–15					0.9972	−0.95
AS*F16–25					1.0062	1.81
AS*F26–45					1.0009	0.19
AS*F46–55					1.0166	2.62
AS*F56–65					1.0101	1.61
AS*F65+					1.0154	2.44
AS*M6–10					1.0058	1.99
AS*M11–15					1.0024	0.80
AS*M16–25					0.9949	−1.89
AS*M26–45					0.9752	−5.90
AS*M46–55					0.9836	−2.66
AS*M56–65					0.9823	−2.26
AS*M65+					1.0071	0.82
AS*Age					.9993	−3.11
AS*Acres					.9983	−1.73
AS*Assets					1.0016	1.48
AS*MaxED					1.0028	3.39
AS*MissMaxED					1.0087	1.20
Log-likelihood	−30490.5		−30467.8		−30415.0	

worked based on the number of males in different age groups except for 0–5 years. The effect is most pronounced for the number of males in the three prime age working categories: 16–25, 26–45, and 46–55. Only the three female categories (6–10 years, 11–15, 16–25) significantly shift the baseline hazard, and these effects are much smaller relative to their male category counterparts. Islamic households provide substantially fewer hours than non-Islamic households. Surprisingly, this is not because women in such households work less, as the interaction terms for the three prime age working categories for females are either insignificant relative to the baseline hazard coefficient of 1 for females (16–25 years) or significantly less than 1 for the next two female age categories. Age of the household head decreases the hazard relative to the baseline, but age squared has the opposite effect. Both variables are not significantly different from 1, but as continuous variables with a large range, they may still be influential. As the level of education of the most educated household member increases, the number of hours the household works decreases, particularly for the most educated. The missing education indicator variable is also associated with working fewer hours, which appears to be somewhat contradictory, since according to other available information, these individuals are apparently less educated in general than those who did provide education levels. However, the coefficient value here is consistent with this group's being a mix of lower education levels rather than having no education. The more cultivatable acres a household has, the more hours it works, although the quadratic term again suggests that this effect tails off as might be expected. Households with more assets work less, with the marginally significant quadratic term again suggesting some tapering effect as assets increase.

Model 2 adds AS and AS squared. A likelihood ratio (LR) test for the addition of AS and AS^2 to model 1 yields a $\chi(df = 2)$ test statistic of 45.36 ($p < .001$).[5] The combination of the two AS variables in (10 μg/L units) suggests fairly sizable negative effects that tail off at arsenic levels that are more than 30 times the WHO standard. Model 3 adds AS interaction terms with various household demographics and assets. An LR test for the inclusion of these twenty interaction terms to model 2 yields a $\chi(df = 20)$ statistic of 105.64 ($p < 0.001$), suggesting that they are jointly highly significant. The effect from arsenic on labor supply increases slightly (compared with models 1 and 2) and remains strong and negative (overall). The first set of new variables are the sex (female or male)/age category variables. Many of these are significant. Females work less, probably to take care of the sick, while males work more, probably to help compensate for the loss in income from reduced work by other household members. Interacted with AS, better educated households work less, and household labor hours increase with the household head's age. Households with more cultivable land increase labor hours worked as arsenic exposure increases relative to households with only outside employment opportunities.

The average percentage effect of eliminating arsenic can be found by taking the average of 1 – (model 3 proportional hazard factor [AS = 0])/(model 3 proportional hazard factor [AS = sample values]) over all sampled households. This results in a 7.9% reduction in household labor supply due to arsenic (which represents 288 hours per year for the average household). The estimated reduction in labor hours from the median household, which has an exposure level somewhat above twice the WHO standard, is substantially smaller at 2.6% (or 95 hours per year). Considering the average daily pay in rural Bangladesh in 2000 (59 takas, or US$1.095 for a daily average of 8 work hours), the annual cost induced by arsenic contamination for the average (median) household is estimated at $(288/8) \times 1.095 = \$39[(95/8) \times 1.095 = \$13]$. If the level of arsenic concentration had an upper limit equal to the WHO (Bangladesh) standard of 10 (50) μg/L, the number of labor hours for the average household would increase by 6.5% (3.6%) compared with the current situation. The corresponding annual monetary valuation is estimated at $32 and $18, respectively.

The impact of arsenic concentration on household labor supply and on intrahousehold labor allocation is illustrated in table 2. We report the marginal impact (in percentage) of arsenic contamination on the number of work hours per year for each sex/age category. This is computed from the estimated parameters of the sex/age category variables and their cross terms with AS. Table 2 reads as follows: in the median household, a woman aged between 45 and 55 works 349 hours per year, but arsenic contamination reduces her labor

[5] A log-specification is clearly rejected in favor of a linear one ($p < 0.001$). Arsenic in the linear specification is also significant at $p < .001$ using two popular alternatives to maximum likelihood standard errors, robust (sandwich) errors, or clustering at the *thana* level, available in STATA 10 under the less accurate Breslow method for ties. The linear specification is rejected in favor of a quadratic specification ($p < 0.001$). While higher-order AS terms were often significant, they appeared to be largely modeling curvature in the far end of the observed AS range, where data are sparse. The AS turning point for model 2 is just past 300 μg/L, where roughly 3% of our data lies, while that of the richer model 3 is 580 μg/L, which is well beyond the range of our AS exposure variable.

Table 2. Marginal Contribution (Work Hours per Year) of Each Demographic Group

Sex/Age Category	Direct Marginal Contribution (median)	Indirect Marginal AS Contribution (median)	Indirect Marginal AS Contribution/Direct Contribution, %
Females 0–5 years of age	−59	–	–
5–10	413	−41	−9.9
10–15	118	15	12.7
15–25	631	−35	−5.5
25–45	−433	−5	1.2
45–55	349	−93	−26.6
55–65	191	−56	−29.3
Over 65	372	−86	−23.1
Males 0–5 years of age	−22	–	–
5–10	464	−32	−6.9
10–15	987	−13	−1.3
15–25	1,429	28	2.0
25–45	1,233	135	10.9
45–55	1,308	90	6.9
55–65	888	97	10.9
Over 65	1,078	−40	−3.7

supply by 93 hours, which represents 26.6% of her initial work load. Our results indicate significant labor substitution as a means to self-insure against the arsenic-induced risk: women over 45 reduce hours worked by about 23–29% (which represents between 56 and 93 hours per year), while men aged between 25 and 65 work more, increasing hours worked by 7–11% (or 90 to 135 hours per year).

Concluding Remarks

In the absence of a structural model, investigating the relationship between arsenic contamination and other variables beyond labor hours is challenging. This is due to the complex endogeneity pattern that may evolve as arsenic contamination influences a household's consumption needs, as well as its ability to accumulate assets (including human capital) and its need to use existing assets. Bypassing some of these issues by using arsenic exposure levels as an instrument, our preliminary analysis suggests that household labor supply in rural Bangladesh is 8% smaller due to the widespread arsenic contamination. Further, our results suggest that an intrahousehold reallocation of work hours is used to self-insure against the risk induced by arsenic contamination. The household's assets and cultivable land are also shown to play a role in how household labor hours respond to arsenic exposure. Clearly there is more work to be done to fully understand the role arsenic contamination plays with respect to household welfare.

Arsenic-induced problems in rural Bangladesh are likely to become worse due to the long latency period for the more serious health impacts of arsenic. Considerable effort is now under way to discourage people from using water from wells with high arsenic concentrations, but information issues related to arsenic concentration remain (Madajewicz et al. 2007). Further, arsenic-related symptoms are often not recognized, and alternatives to current shallow tube wells either are very expensive or involve walking long distances to obtain uncontaminated water.

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