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Arsenic Mitigation in Bangladesh
A Household Labor Market Approach

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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

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large sample of rural households matched to arsenic exposure, we find (i) overall household labor supply is 8% smaller due to arsenic exposure and (ii) intra-household reallocation of work between males and females is used to self-insure against the risk induced by arsenic exposure.

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 the groundwater resources of the country 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 61 out of 64 districts of Bangladesh between 1998 and 1999. The results show that 27 percent of the tube wells less than 150 metres deep exceeded the Bangladesh standard for arsenic in drinking water of 50 µg/litre. Using the World Health Organisation (WHO) guideline value of 10 µg/litre as the reference level the figure rises to 46 percent. It is now believed that around 35 million people are exposed to an arsenic concentration in drinking water exceeding 50 µg/litre, whilst 57 million people are exposed to concentration levels exceeding 10 µg/litre.

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 keratoses – a condition in which painful nodules grow on the palms of 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 10 years. The initial effects of chronic arsenic exposure are a feeling of general lethargy coupled with mild headaches and confusion, effects which 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 focused on an epidemiological approach that tried to effectively monetize a dose response relation either using a cost of illness or 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., Graff-Zivin, Thirumurthy and Goldstein 2009; d'Adda, et al. 2009). The main findings from this literature are that AIDS treatment results in significant intra-household 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 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 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 diseases 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 toward 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 (non-biologically 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 *thana* level, 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 story with the relevant coefficients tending to be biased toward zero. Our identification strategy effectively relies on the cross-thana variation strongly dominating within 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 located 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 because of 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, 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 to control for the household's religion (1 for Islam and 0 otherwise), the age of the reported head of household (typically the oldest male), the maximum education level of any household members and an indicator variable for the sizeable fraction of the sample who do not report an education level (and from other indicator variables appear to have low education levels), as well as for two continuous asset related variables. The first of these is the households' overall wealth and the other is the quantity of cultivable land owned. The base model also employs squared versions of these variables and the most comprehensive model includes interactions with the arsenic exposure level.

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's characteristics. A simple version of the labor supply model can be written as follows:

$$HHW_i = \alpha X_i + \beta AS_i + \theta X_i AS_i + \mu_i,$$

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

We are interested in three issues. The first is whether arsenic contamination is 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 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.

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 which enforces non-negativity and typically assumes a finite upper bound support. One can either fit a parametric survival specification like the Weibull or a semi-parametric 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 proportionate 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:

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

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 is zero. For sizeable 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.

Data

Our sample is comprised of 4,259 rural Bangladesh households from the Household Income and Expenditure Survey (HIES) carried out by the Bangladesh Bureau of Statistics (BBS) in 2000 which 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/litre, which is above both the WHO and Bangladesh standards of 10 and 50 µg/litre, respectively. Arsenic exposure levels varying from a low of 0.3

μg/litre to a high of 421 μg/litre (descriptive statistics are available upon request). Our arsenic variable is scaled in 10 μg/litre units, which can be thought of 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 worked based on the number of males in different age groups except for [0-5]. The effect is most pronounced for the number of males in the three prime age working categories: [16-25; 26-45; 46-55]. Only the three female categories [6-10; 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] and significantly less than one 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 one, but as continuous variables with a large range 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 somewhat contradictory since these individuals appear using other available information to be less educated in general than those providing education levels. However, the coefficient value here is consistent with this group being a mixture of the 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 χ(df=2) test statistic of 45.36 ($p < .001$).[5] The combination of the two AS variables in (10 µg/litre units) suggests fairly sizeable 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. A LR test for the inclusion of these 20 interaction terms to Model 2 yields a χ(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 to models 1 and 2) and remains strong and negative (overall). The first set of new variables is the sex [F or M]/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 proportionate hazard factor [AS=0]/[Model 3 proportionate 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 responses is substantially smaller at 2.6% (or 95 hours per year). Considering the average daily pay in rural Bangladesh in 2000 (59TK 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) x 1.095 = US$39 [(95/8) x 1.095 = US$13]. If the level of arsenic concentration had an upper limit equal to the WHO [Bangladesh] standard of 10 [50] μg/litre, the number of labor hours for the average household would increase by 6.5% [3.6%] compared to the current situation. The corresponding annual monetary valuation is estimated at US$32 and US$18, respectively.

The impact of arsenic concentration on household labor supply and on intra-household 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 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 to 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 suggested that an intra-household 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 are either very expensive or involve walking long distances to obtain uncontaminated water.

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Table 1. Results From Cox Proportional Hazard Models

Variable	Model 1	z-statistic	Model 2	z-statistic	Model 3	z-statistic
Female 0-5	1.0116	0.45	1.0048	0.18	1.0192	0.73
Female 6-10	0.9067	-3.72	0.9073	-3.70	0.8544	-4.54
Female 11-15	0.9465	-1.86	0.9394	-2.11	0.9616	-1.10
Female 16-25	0.7834	-2.62	0.7877	-2.56	0.7946	-2.41
Female 26-45	1.1312	1.19	1.1093	1.00	1.1410	1.19
Female 46-55	1.0039	0.03	1.0008	0.01	0.8864	-0.79
Female 56-65	1.0170	0.32	1.0093	0.18	0.9380	-0.97
Female 65+	0.9754	-0.39	0.9585	-0.67	0.8790	-1.61
Male 0-5	1.0008	0.03	0.9899	-0.39	1.0072	0.27
Male 6-10	0.8755	-5.07	0.8779	-4.96	0.8489	-5.18
Male 11-15	0.6903	-12.86	0.6885	-12.95	0.6786	-11.16
Male 16-25	0.5255	-24.08	0.5212	-24.40	0.5350	-19.31
Male 26-45	0.5157	-17.76	0.5083	-18.14	0.5988	-11.20
Male 46-55	0.5239	-11.24	0.5201	-11.38	0.5743	-7.89
Male 56-65	0.6356	-6.40	0.6271	-6.58	0.7111	-3.96
Male 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	1.000	1.47	1.000	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*(HHSize < 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	

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 between 0 and 5	-59	-	-
Females between 5 and 10	413	-41	-9.9%
Females between 10 and 15	118	15	12.7%
Females between 15 and 25	631	-35	-5.5%
Females between 25 and 45	-433	-5	1.2%
Females between 45 and 55	349	-93	-26.6%
Females between 55 and 65	191	-56	-29.3%
Females over 65	372	-86	-23.1%
Males between 0 and 5	-22	-	-
Males between 5 and 10	464	-32	-6.9%
Males between 10 and 15	987	-13	-1.3%
Males between 15 and 25	1,429	28	2.0%
Males between 25 and 45	1,233	135	10.9%
Males between 45 and 55	1,308	90	6.9%
Males between 55 and 65	888	97	10.9%
Males over 65	1,078	-40	-3.7%

Endnotes

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[1] Hours worked variable includes wage employment and self-employment in non-agricultural and agricultural sectors for in-kind remuneration, including working on household land plot.

[2] Recall that if f(t) is the density and F(t) the CDF then the survival function is 1 – F(t) and the hazard function is f(t)/S(t). F(t) and S(t) are easy expressed in terms of the integrated hazard rate.

[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 who do not rely on tube wells (which represents 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 who 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.

[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 ML 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/litre where roughly 3% of our data lies, while that of the richer Model 3 is 580 μg/litre, which is well beyond the range of our AS exposure variable.