Environment and Development Economics, page 1 of 17. © Cambridge University Press 2013
doi:10.1017/S1355770X13000612

Evolution of households' responses to the groundwater arsenic crisis in Bangladesh: information on environmental health risks can have increasing behavioral impact over time

SOUMYA BALASUBRAMANYA (Co-lead author)
International Water Management Institute, 127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka. Tel. +94 11 2880000.
Email: s.balasubramanya@cgiar.org

ALEXANDER PFAFF (Co-lead author)
Sanford School of Public Policy, Duke University, USA.
Email: alex.pfaff@duke.edu

LORI BENNEAR
Nicholas School of the Environment, Duke University, USA.
Email: lori.bennear@duke.edu

ALESSANDRO TAROZZI
UPF and Barcelona GSE, Department of Economics and Business, Spain.
Email: alessandro.tarozzi@upf.edu

KAZI MATIN AHMED
Department of Geology, University of Dhaka, Bangladesh.
Email: kmahmed@univdhaka.edu

AMY SCHOENFELD
Lamont-Doherty Earth Observatory, Columbia University, USA.
Email: avgeen@ldeo.columbia.edu

ALEXANDER VAN GEEN
Lamont-Doherty Earth Observatory, Columbia University, USA.
Email: avgeen@ldeo.columbia.edu

Submitted 2 October 2012; revised 4 September 2013; accepted 14 October 2013

ABSTRACT. A national campaign of well testing through 2003 enabled households in rural Bangladesh to switch, at least for drinking water, from high-arsenic wells to neighboring lower arsenic wells. We study the well-switching dynamics over time by re-interviewing, in 2008, a randomly selected subset of households in the Araihazar region who had been interviewed in 2005. Contrary to concerns that the impact of arsenic information on switching behavior would erode over time, we find that not only was 2003–2005 switching highly persistent but also new switching by 2008 doubled the share of households at unsafe wells who had switched. The passage of time also had a cost: 22 per cent of households did not recall test results by 2008. The loss of arsenic knowledge led to staying at unsafe wells and switching from safe wells. Our results support ongoing well testing for arsenic to reinforce this beneficial information.

1. Introduction

Groundwater arsenic poses a significant health risk for tens of millions of people in South and Southeast Asia. In 2000 roughly half of the population of Bangladesh were consuming groundwater with arsenic above the World Health Organization's 10 μg/L safety standard, with one-third having arsenic above the national standard of 50 μg/L (World Bank, 2005). Arsenic has many negative health effects – with latency periods of 5–15 years for earlier effects and 20 or more years for cancers (Argos *et al.*, 2010; Chen *et al.*, 2011). In Bangladesh, well testing has been the critical spur for households to switch away from arsenic-unsafe wells, at least for drinking. We examine the evolution of the well-switching responses by households to gauge whether the tests' impact on switching behavior eroded or increased over time. We also document a loss of test information that affects switching.

Until the 1970s, water in ponds was the primary source of drinking water in Bangladesh. Groundwater from tube wells (often 30–100 m deep) was promoted to reduce water-borne disease, a leading cause of high infant mortality rates. Most wells were privately installed, given low costs of installation and the convenience and privacy of having one's own well (Caldwell *et al.*, 2003). By 1990, groundwater was the main drinking source for over 90 per cent of the population and over 95 per cent in the rural areas (World Bank, 2005). It was not known at that time that the groundwater contained naturally occurring arsenic. Testing later revealed significant contamination in Bangladesh, leading the World Bank to create the Bangladesh Arsenic Mitigation Water Supply Program (BAMWSP), which tested five million tube wells countrywide using field kits, for free, during 1999–2003. Wells with arsenic above 50 μg/L were painted red ('unsafe'). Those with arsenic below 50 μg/L were painted green ('safe').

For funding, the authors thank the Duke Centre for Comparative Biology of Vulnerable Populations, the Arts and Science Committee on Faculty Research, and the Students International Discussion Group at Duke's Nicholas School of the Environment. The original 2005 survey was supported by NIEHS Superfund Research Program grant P42 ES10349. The authors are particularly grateful to the survey team of 30 graduate students at the University of Dhaka for their excellent work during data collection. From this journal the authors thank two anonymous referees and an anonymous associate editor for helpful comments; they also thank Randall Kramer, Chris Timmins, Jeff Vincent, and many seminar participants including those at Duke University's Population and Development Seminar, Duke University's Nicholas School of the Environment PhD seminar series, Columbia University, CATIE and Camp Resources XVI.

Arsenic levels – determined by the local geology – can vary greatly even within a village (British Geological Survey, 2001; van Geen *et al.*, 2002, 2006). Thus, well testing and labeling for arsenic could encourage 'well switching' away from unsafe wells, i.e., choosing not to drink water from unsafe wells and, instead, drinking from safer wells. BAMWSP's tests motivated households whose wells were painted red to switch wells – often to neighbors' safe wells but sometimes to safe community wells (Ahmed *et al.*, 2006). At least in the short run, reductions in arsenic exposure achieved through well testing and switching have been larger than that achieved via any other means (Ahmed *et al.*, 2006).[1]

It has been suggested, however, that households might return to their prior wells over time (Hanchett *et al.*, 2002). That could follow from a reduced supply of safe wells if their owners stopped providing access, due to increased pump wear-and-tear or concerns about privacy. Demand for safe wells also could decline if concerns about arsenic fade after unsafe tests. Yet early switches could lead to later switching. Observing switching by neighbors could increase perceived gains from safe water or lower perceived costs of using others' wells – either of which could lead to leaving an unsafe well later, after having initially stayed put. Thus, there are reasons to believe that well switching could either fall or rise across time.

We examine the medium-run impacts on well switching of BAMWSP's pre-2003 arsenic testing, within one sub-district of Araihazar. In 2008, we conducted a follow-up survey to record well switching during 2005–2008 among a randomly selected subset of households whose initial well-switching behaviors, during 2003–2005, had been recorded previously. Successive decisions by each household, over time, permit us to evaluate whether impacts of arsenic testing on household well-switching behavior eroded or increased over time. We believe this is the first study of switching over time for arsenic. It is one of few examining the longer run impacts of health information interventions (see also Nyström *et al.*, 2002; Ozminkowski *et al.*, 2002; Beardslee *et al.*, 2007, all concerning developed countries).

Our results suggest that arsenic testing produced increasing behavioral response over time. Of households at unsafe wells who had switched wells by 2005, 88 per cent were at the 2005 well in 2008. None went back to old wells. Of households at unsafe wells who had not switched by 2005, a significant share switched by 2008, doubling the share of households who had ever switched from unsafe wells. In this case, information's impact increased over time.

Yet we do see one cost of the passage of time. The recollection of test results fell, as 22 per cent of households recalled their 2003 arsenic test results in 2005 but, by 2008, were unable to do so. Switching by households with inaccurate recall was more common from safe wells than from unsafe,

[1] The World Bank produced a detailed report on responses to the arsenic crisis in South and Southeast Asia, which considers a number of strategies for avoiding arsenic, including ponds with sand filters and river water. We recommend that report to compare strategies but we focus, in this paper, on the best strategy until now.

a pattern opposite to that for households with accurate recall of arsenic. That too supports ongoing arsenic tests to reinforce this useful information intervention.

Below, section 2 provides a brief review of the empirical literature concerning roles of health-risk information in health-improving behavior, with a focus in particular upon Bangladesh. Section 3 then sketches several conceptual perspectives on the dynamics of well switching, which suggest testable hypotheses. Section 4 describes our data and provides descriptive statistics, while section 5 presents our results and section 6 discusses their implications.

2. Related empirical literature

2.1. Information provision and health-improving behaviors

In public health, information campaigns have been used to promote safer sexual practices (Alstead *et al.*, 1999), regular monitoring of health (Fender *et al.*, 1999; Black *et al.*, 2002), cessation of smoking (Siegel and Beiner, 2000; Farrelly *et al.*, 2002), and reduction in transmission of infectious diseases (Preston, 1996). Nutrition labels on food products aim to motivate appropriate choice in one's diet (some relatively recent examples are Harnack and French, 2008; Downs *et al.*, 2009; Wisdom *et al.*, 2010).

Information provision about health in developing countries has confronted leading causes of heavy disease burdens to motivate exposure-reducing practices including better hygiene, vaccination and choices to reduce HIV risk (Sircar *et al.*, 1987; Stanton and Clements, 1987; Siriwardena *et al.*, 2002; Fewtrell *et al.*, 2005; Jalan and Somanathan, 2008; Thornton, 2008; Pattanayak and Pfaff, 2009; Kennedy *et al.*, 2010; Pattanayak *et al.*, 2010). Developing country governments may be challenged to provide the desired environmental conditions (e.g., clean air and water) and may lack the institutional and technological capacity to ensure adherence to environmental and health standards or respond to disease outbreaks. When they possess risk information, individuals can take action to help avoid health risks.

Research on health information's impacts suggests that it motivates better health practices but also that its effects are likely to vary with risk, education and income (see, e.g., Shimshack *et al.*, 2007; Jalan and Somanathan, 2008). Most of this evidence has been based on data for two years or less (such studies include, e.g., Duflo *et al.*, 2006; Dupas, 2010), thus not much is known about whether behavioral changes vanish, persist or even expand.

2.2. Arsenic information and exposure-reducing behaviors

BAMWSP conducted countrywide arsenic testing of the groundwater from wells between 1999 and 2003. In a 25 km^2 area of Araihazar region, however, well tests were provided in 2000 by a team of researchers from Columbia University (van Geen *et al.*, 2003). Much of the prior study of behavioral impacts from arsenic testing has been done within this area.

Madajewicz *et al.* (2007) conducted a survey of household behaviors in this 25 km^2 area. They found that general information on arsenic risks, as disseminated through television, did not lead to well switching. However, specific well tests led over half of those at unsafe wells to switch, despite walking costs. For the same area, Opar *et al.* (2005) found one year later that almost two-thirds of the households at unsafe wells had switched – albeit in some cases to untested wells – versus only 15 per cent of the households at safe wells having switched. Both articles indicated that distance to a safe well, and whether one owned the unsafe well, were important factors in well switching. Again for this area, Chen *et al.* (2007) considered the combined effect of an in-person communication of tests alongside health information, well labeling and village-level education. This study found that urinary arsenic levels had dropped over time among the individuals in those households that reported well switches, while not changing much for individuals in households that reported not having switched.

This sub-region of Araihazar may be influenced by the presence of Columbia University's team. Schoenfeld (2005) surveyed other areas within Araihazar where the well testing had been provided by BAMWSP alone, to limit the impact of the research program, and found lower although still significant impacts of well testing within these BAMWSP-only areas.

3. Conceptual frameworks

Existing static models consider tradeoffs faced by households choosing among strategies for arsenic-exposure reduction, including whether to act at all to reduce arsenic exposure. In the spirit of the models within Grossman (1972) and Freeman (1993), Madajewicz *et al.* (2007) describe a household that maximizes utility, assumed to be a function of illness and the consumption of leisure and other goods. Facing both income and time constraints, the household allocates some of each to reduce illness through both prevention and treatment. Factors affecting allocation are exogenous exposure (arsenic in one's well) and exogenous prices for prevention (for instance, walking time to a safe well in order to avoid exposure).

Net benefits of switching may change over time, however, which can affect well switching. Switching's net benefit might fall over time, leading households to reverse prior switching. Hanchett *et al.* (2002) and Caldwell *et al.* (2003) claim that the risk from arsenic is unclear for many households – especially given public endorsement of groundwater in the 1970s – so that arsenic risk information may need to be reinforced to dissuade the use of unsafe wells. Arsenic concern could also fall over time if risk perceptions fall with the time after the risk information is presented (Karlan *et al.*, 2010, for example, highlights this possibility). Households may also switch back to unsafe sources if safe-well owners reduce access to their wells – offering access in a crisis while expecting such usage to end (Fehr and Fischbacher, 2003). Along these lines, Hanchett *et al.* (2002) describe the sense of humanitarian outreach when news of an arsenic contamination crisis broke but also note, based on detailed interviews, that rising social tensions led those still drinking from unsafe wells to sometimes claim that no safe alternatives were available despite low-arsenic wells being present in the vicinity.

On the other hand, net benefits of switching could rise over time – increasing switching if that rise in net benefits is sufficient for households to switch later after staying put earlier. Such a rise could be due to a new exogenous supply of information on the risk from arsenic; however, within our study area, no new arsenic well tests had been carried out since 2003. Information may also be acquired by observing neighbors' behaviors, leading households to mimic early switchers. Alternatively they may adjust their perceptions of factors which drive switching, for instance raising their perceptions of risk from arsenic or lowering their perceptions of costs of using others' wells, by inferring from neighbor actions (research on such 'social learning' includes Miguel and Kremer, 2004; Munshi and Myaux, 2006).

The net perceived benefits of switching also vary with the arsenic level in the well that is currently used for drinking – and even that information can change, with implications for well switching over time. With no retesting for arsenic after 2003, the red and green paint that was applied by BAMWSP could and did wash away by 2008. Such loss of information can change perceptions of what is safe. Well switching could increase if those at safe wells come to think that their wells are unsafe. On the other hand, households with unsafe wells who may have switched later would not do so if they came to believe their wells were safe.

4. Data and descriptive statistics

4.1. Data

We revisited a randomly selected subset of the households studied by Schoenfeld (2005). The sample frame for that study of 2003–2005 switching was a database with 30,000 test results from BAMWSP (table 1). Schoenfeld (2005) selected eight villages in Araihazar with over 80 per cent unsafe wells and 54 villages with 40–60 per cent of unsafe wells. Each village received arsenic test results from BAMWSP, i.e., not from university researchers. In each of the 62 villages, the 2005 field team surveyed all of the wells that BAMWSP had tested and approached well owners' wives (or a close female relative) to conduct a short survey. A total of 3,056 households were interviewed (at 3,056 distinct wells, i.e., one per well).

We returned during January–April of 2008 to record the well switching during 2005–2008. We exclude from our analyses: one village with 52 surveyed households, where we pre-tested our survey; and two villages with six surveyed households, due to time constraints. In each of the remaining 59 villages, a random number was generated for each well listed in the 2005 study and the interviews were conducted in ascending order of those numbers. We could not interview all households, thus those living within villages with fewer (more) households are over (under)-sampled. To address these unequal probabilities of selection we use sampling weights, finding no statistically significant differences between results with and without weights. Our 2008 sample includes 1,557 households from 59 villages.

The Bangladesh Medical Research Council and Columbia's Institutional Review Board approved the 2005 well testing and test reporting in Araihazar. The 2005 field team recorded the Global Positioning System

Table 1. *Sources and timeline for key variables*

	2005	*2008*
Selection into study		
Which villages	X	
Sample frame	X	
Households for 2005 survey	Surveyed all households that owned a tubewell	
Households for 2008 survey		Random sample of well owners visited by Schoenfeld 2005
Data collection		
Switching during 2003–2005	X	X
Switching during 2005–2008		X
Paint color observed on well	X	
Perception of tested well in 2005	X	
Perception of tested well in 2008		X

(GPS) coordinates of the well, the color of paint applied to the well by BAMWSP (if still visible), respondents' recollections of their test result, and self-reported switching behavior for 2003–2005 (see table 1 for data timing). The Institutional Review Board for the Protection of Human Subjects in Non-Medical Research at Duke University approved the 2008 study in Araihazar (protocol #2184). Informed consent was obtained at the start of the interviews. In the 2008 survey, we recorded self-reported well switching for 2005–2008 and for 2003–2005, recollections of test results, socioeconomic indicators and motivations for leaving wells during 2003–2008.

As we asked households in 2008 to again recall their switching choices during 2003–2005, we were able to check the consistency of reported behavior by comparing these responses with what was reported about 2003–2005 switching to Schoenfeld (2005). In 78 per cent of cases, the responses matched (table 2, column 2c totals). Among those 22 per cent where responses did not match, 12 per cent of households reported in 2005 that they switched during 2003–2005 but then reported in 2008 that they had not, while 10 per cent of the households reported in 2005 that they had not switched during 2003–2005 but then reported in 2008 that they had switched.

We also compared recollections of well safety across the 2005 and 2008 surveys to check for consistency in the recall of well-test results. We merged the 2008 responses regarding the perceived safety of wells tested by BAMWSP with observations made in 2005 regarding the color applied to the well by BAMWSP, as well as the households' perceptions in 2005 about the arsenic safety of the same well. We find that 78 per cent of households consistently recalled their well-safety perceptions in both 2005 and 2008 (table 2, column 1c totals).

Table 2. *Recall: 2003 test results and 2003–2005 switching behavior*

	Recall of 2003 tests in 2005 and in 2008			*Recall of 2003–2005 switching in 2005 and in 2008*			*Overall recall*
	(1a)	*(1b)*	*(1c)*	*(2a)*	*(2b)*	*(2c)*	*(3) {1c & 2c}*
	2005 Safety recall = 2003 Paint	2008 Safety recall = 2003 Paint	2005 & 2008 Safety recall = 2003 Paint	2005 & 2008 Behavior recall = Switching 2003–2005	2005 & 2008 Behavior recall = NoSwitch 2003–2005	2005 & 2008 Behavior recall is consistent over time	Consistent recall of both safety & behavior thru 2008
Red = Unsafe (1,038 obs.)	97%	79%	77%	11%	59%	70%	55% (575 obs.)
Green = Safe (519 obs.)	95%	83%	81%	0%	94%	94%	79% (410 obs.)
TOTAL (1,557 obs.)	96%	80%	78%	7%	71%	78%	63% (985 obs.)

Notes: Columns 1a, 1b and 1c report the percentage of unsafe, safe and total households whose recollections of test results matched the color of paint applied on the well-heads in 2003, and observed by the study team in 2005.
Columns 2a and 2b report the percentage of safe, unsafe and total households with consistent recollections of 2003–2005 switching decisions (with those who switched in 2a and those who did not in 2b). Households were asked to report 2003–2005 behavior in 2005 and again asked to report 2003–2005 behavior in 2008.
Column 3 reports the percentage of unsafe, safe and total households who consistently recalled both of their arsenic test results and their 2003–2005 switching behaviors, from 2003 through 2008, i.e., our core sample.

Table 3. *Descriptive statistics*

	Full sample		*Unsafe – Safe*		*Switch – Didn't*	
	Mean	*Std. Err.*	*Mean*	*Std. Err.*	*Mean*	*Std. Err*
Monthly income (takas)	8,186	8,569	−88.8	473.13	64.33	543
Brick walls	0.13	0.33	−0.02	0.01	0.07	0.03***
Uses a latrine	0.81	0.39	0.02	0.03	0	0.03
Respondent age	40	13.33	−0.28	0.85	−0.46	0.88
Respondent literate	0.44	0.5	0	0.03	0.07	0.03**
Household size	5.6	2.44	−0.12	0.13	−0.1	0.2
Fraction with unsafe wells	0.68	0.48	n/a	n/a	0.27	0.03***
Fraction with arsenic symptoms	0.09	0.28	0.05	0.03**	0.01	5.14
Distance to closest safe well (m)	32	51.47	46[a]	5.69***	5[b]	2.89*

Notes: *, ** and *** denote significance at 10%, 5% and 1%, respectively.
[a]The distance to safe for households with safe wells is zero, so this is the average for unsafe wells.
[b]The distance to safe is higher for those who switch because most switching is from unsafe wells, influencing also the coefficient in table 5, which differs if studying unsafe wells (as in table 4).
Source: Authors' 2008 survey, all calculated using sampling weights and clustering at the village level.

4.2. Descriptive statistics

For our full sample of 1,557 households, the average number of household members was six (table 3). Almost all interview respondents (98 per cent) were female heads of household, i.e., those primarily responsible for water-source choices. Respondents were 40 years old on average, often illiterate (44 per cent could read and write in *Bangla*), and had a relatively low mean monthly household income (8,186 Takas, or US$356 using a purchasing power parity rate of 23 Takas to US$1, World Bank, 2008). While 81 per cent of households had access to a latrine, only 13 per cent owned dwellings with brick walls. Self-reports indicated that 9 per cent had at least one member who had displayed symptoms of related illnesses. Across all households, the average distance to a safe well was 32 m (Schoenfeld, 2005), consistent with our prior finding that most of the households in this area were not far from at least one safe source.

5. Results

Before focusing on the evolution of well-switching responses, we confirm that on average arsenic testing influenced well switching across our full two-period sample of 1,557 wells.[2] About one-third (519) of the sample

[2] This average, which blends the time periods that are our focus, is to confirm consistency with prior analyses (see section 2.2). For our study region with BAMWSP tests, it just extends Schoenfeld's (2005) analysis out to 2008.

households received a safe test result from BAMWSP by 2003. Of these, 85 per cent never switched wells by 2008. Of the two-thirds (1,038) of sample households that received unsafe results in 2003, 59 per cent never switched by 2008. Thus, more switching was observed at unsafe wells as fewer stayed put than at safe wells ($p < 0.0001$).

Table 4 repeats the comparison above, controlling for factors that affect switching such as household income and distance to a safe well, which we use henceforth in all regressions.[3] We also want to address any incorrect recall by restricting our sample to households with consistent recall over time of arsenic-test results and well switching during 2003–2005.[4] Most households recalled their pre-2003 arsenic test results correctly in 2005 and in 2008 (77 per cent of unsafe, 81 per cent of safe; table 2, column 1c) and most households consistently recalled their 2003–2005 decisions about whether or not to switch (70 per cent of unsafe, 94 per cent of safe; table 2, column 2c).[5] Combining these filters, 985 households (575 or 55 per cent of unsafe, 410 or 79 per cent of safe) consistently recalled both test results and 2003–2005 switching through 2008 (table 2, column 3). As in column 2 of table 4, we focus on these 985 households controlling for other factors.

5.1. Did the behavioral impact of arsenic testing erode or increase over time?

We examine first the 2005–2008 choices by those 985 households with consistent test and behavior recall (in section 5.2 we study inconsistent recall and the impacts of lost arsenic information). For those who had switched in the first period, we check whether switches were persistent. For households who had not switched in the first period, we look for later well switching. Test impacts may erode if early well switching is reversed later, and that effect dominates. Yet impacts can rise if early well switching is persistent and later well switching occurs.

[3] Evidence from Araihazar finds arsenic levels uncorrelated in villages with household and site characteristics (see, e.g., Madajewicz *et al*., 2007). Thus, table 4 can reveal a causal link between arsenic and switching.

[4] While surveying for recall, we also asked households to self-report their motivations for switching wells. These differ between households who left safe and unsafe wells. Households who switched away from safe wells more often reported reasons that are unrelated to arsenic, the most common one being that their wells simply had stopped functioning (20 per cent). This reason was less common (13 per cent) for switches from unsafe wells.

[5] Imperfect recall of past behaviors may have implications for the categorization of a household's behavior. Behavior during 2005–2008 was recorded only in the 2008 survey, while behavior during 2003–2005 was elicited in both the 2005 and 2008 surveys. Using the 2008 survey data for switching choices during 2003–2005, we categorize households as switching 'never' (67 per cent), 'early' (14 per cent), 'late' (15 per cent), and 'early and late' (4 per cent) while using 2003–2005 switching reported in 2005 we find never (66 per cent), early (15 per cent), late (14 per cent), and early and late (5 per cent). A χ^2 test for a difference between these two behavior categorizations was unable to reject the null hypothesis of no difference at either the 5 per cent or the 10 per cent level of confidence ($p < 0.22$).

Table 4. *Well switching and arsenic test results*

Probit regressions (marginal effects)	*(1) Ever switched?*	*(2) Ever switched?*	*(3) Switched late? (if didn't early)*
	All observations	*Consistent recall: both safety & past behavior*	*Consistent recall: both safety & past behavior*
Unsafe BAMWSP well	0.29	0.31	0.13
	(0.04)***	(0.04)***	(0.04)***
Household income	−0.001	−0.001	−0.001
	(0.001)	(0.002)	(0.00)
Does the dwelling have brick walls?	0.15	0.13	0.11
	(0.04)***	(0.05)***	(0.03)***
Does the household use a latrine?	0.04	0.03	0.01
	(0.04)	(0.04)	(0.03)
Respondent's age	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)
Is respondent literate?	0.01	0.04	0.02
	(0.03)	(0.03)	(0.03)
Household size	0.001	−0.002	0.004
	(0.01)	(0.001)	(0.01)
Distance to safe well (m)	−0.001	−0.001	0.0001
	(0.0003)**	(0.0005)***	(0.0003)
N	1,409	884	809
F-statistic	$F(8, 51) = 7.17$	$F(8, 51) = 9.81$	$F(8, 51) = 3.89$
Prob > 0	0.0000	0.0000	0.0012

Notes: Binary dependent variable is equal to one if the household switched from the well during the time period.
All regressions consider the households that recalled their switching behaviors during 2003–2005 consistently. In columns 2 and 3, we additionally filter observations to only those households who consistently perceived the arsenic status of their well correctly in both the 2005 and 2008 surveys.
Perfect recall indicates that the households were able to consistently report their 2003 test result in 2005 and in 2008, along with consistently reporting their 2003–2005 switching behaviors in both 2005 and 2008.
Estimates are adjusted using sampling weights, and have been corrected for intra-village correlation.
Standard errors are in parentheses, with *, **, *** indicating significance at 10%, 5% and 1%, respectively.
Source: Authors' calculations from 2005 and 2008 survey.

5.1.1. Persistence of early switching away from arsenic-unsafe wells

We consider the hypothesis that some early switchers who had switched during 2003–2005 might have returned during 2005–2008 to the unsafe wells that they had left earlier. In fact, we find that the vast majority of early switchers from unsafe wells stuck with their choices. Of the 16 per cent of households at unsafe tested wells who had switched wells during 2003–2005, 14 per cent (or almost 88 per cent of the early switchers) did not switch wells again during 2005–2008. This implies a very high level of persistence of early switching. Further, not one of the 2 per cent at unsafe wells who switched twice moved back in 2005–2008 to their 2003 unsafe well (two-thirds reported the later switches as being to another well they perceived to be safe).

5.1.2. Arsenic testing's impact on late switching for early non-switchers

We consider next the hypothesis that some of the households who did not switch earlier decided to switch wells later, i.e., during 2005–2008 – and we find that 17 per cent of them did. Given a 16 per cent rate of early switching from unsafe wells, the second-period well switching approximately doubles the fraction of households who had ever switched wells by 2008.

To link the 2005–2008 switching to arsenic tests that BAMWPS had provided before 2003, we check whether the late switching rates differ for households with safe and unsafe wells and, in particular, for households mentioning arsenic as one driver of switching decisions. Of the 128 households at unsafe wells who explicitly mentioned arsenic as one motivation, 26 per cent switched wells only later. In contrast, of the 372 households at safe wells who stated that they perceived their water was arsenic safe, not even 1 per cent switched during 2005–2008.

We formalize such a comparison in the regression presented in column 3 of table 4, where we show that households with unsafe wells who did not switch early were 13 per cent more likely to switch wells late than were those households at safe wells who had not switched early. The difference is statistically significant, highlighting the underlying fact that while 54 per cent of our sample is at unsafe wells, 75 per cent of 2005–2008 switches took place at unsafe wells.

5.2. Would it help to reinforce the provision of arsenic information?

We next consider the effects of a loss of arsenic information over time on well switching. Arsenic-safety perceptions changed by 2008 for 22 per cent of 1,557 households (table 2, column 1c). In 2005, BAMWSP's paint was visible on all 1,557 wells (1,038 unsafe, 519 safe) and almost all households (97 per cent at unsafe, 95 per cent at safe) recalled the arsenic safety of primary drinking wells (table 2, column 1a). By 2008, paint was rarely discernible. Only 77 per cent of those households at unsafe and 81 per cent at safe wells correctly recalled the 2003 well-test results (table 2, column 1c).

Table 5 links the changes in arsenic recall to well-switching decisions during 2005–2008. Column 1 shows that safety perceptions are critical by including as explanatory factors not only safety perceptions but also tested well safety. A perceived lack of safety raises switching. Tested safety, in contrast, appears to reduce switching. That is driven by those households at unsafe wells who came to believe their wells were safe and did not switch, along with households at safe wells who came to believe their wells were unsafe and thus switched.

Column 2 looks at households with inaccurate recall to study its switching consequences. Starting with statistics, among safe-well households who changed their safety perceptions, 26 per cent switched in 2005–2008,

Table 5. *Well switching and arsenic test recall*

PROBIT REGRESSIONS (1 = SWITCHED LATE)	*Switched late? (if not early) Correct test recall in 2005 Consistent behavior recall*	*Switched late? (if not early) Correct test recall in 2005 Consistent behavior recall but Incorrect test recall in 2008*
Perceived well unsafe in 2008	0.21 (0.04)***	
Well tested unsafe (BAMWSP)	−0.09 (0.05)**	−0.24 (0.09)***
Household income	−0.001 (0.002)	0.0001 (0.01)
Does dwelling have brick walls	0.14 (0.03)***	0.35 (0.14)
Does household use a latrine	0.01 (0.03)	0.05 (0.08)
Respondent's age	0.001 (0.001)	−0.003 (0.002)
Is respondent literate	0.03 (0.03)	0.01 (0.07)
Household size	0.003 (0.01)	−0.01 (0.02)
Distance to safe well (m)	0.00003 (0.0003)	0.002 (0.001)***
N	901	147
F-statistic	$F(10, 49) = 6.4$	$F(8, 39) = 3.61$
Prob > 0	0.0000	0.0031

Notes: Estimates are adjusted using sampling weights, and have been corrected for intra-village correlation.
Standard errors reported in parentheses. *, **, *** indicate significance at 10%, 5% and 1%, respectively.
Source: Authors' calculations from 2005 and 2008 survey.

while among those at unsafe wells who changed perceptions only 11 per cent switched in 2005–2008. Thus, the loss of information yielded perverse switches. Column 2 of table 5, for households who did not switch early, links actual well safety to switching in 2005–2008 conditional on inaccurate test recall. Households at unsafe wells had a 24 per cent lower probability of switching ($p < 0.01$) – suggesting a potential impact from reinforcing information about arsenic risk to reduce the probability of perverse switching.

6. Discussion

We found that the behavioral responses to arsenic tests of well water increased over time, due to the persistence of early well switches alongside new switches in the second period. We also found a significant share of households who, by 2008, could no longer recall the test results provided before 2003. This loss of information affected behavior perversely.[6]

[6] Along these lines, it could be that once a household has chosen to not switch away from an unsafe well, they no longer wish to recall that it is unsafe (psychological research on 'confirmation bias', for example, suggests people seek out information in support of and ignore information that goes against their actions (Nickerson, 1998; Jones *et al.*, 2001)). For our limited set of incorrect-2008-recall observations,

Testing wells is cheap, at least compared to solutions such as piping and treatment of water (World Bank, 2005; Johnston *et al.*, 2010). Our results suggest that inexpensive tests led to departures from unsafe wells within two years which persisted at least another three years, plus further well switching years after testing. Nationwide, switching following testing is responsible for most of the reduction in arsenic exposure in Bangladesh to date (Ahmed *et al.*, 2006). Yet well testing still receives less attention than capital-intensive interventions.

Nothing better demonstrates that lack of attention than the fact that no public well testing has occurred since 2003. In 2008, we found that one-fifth of households could no longer recall accurately the test results they had received before 2003. With the passage of time such a loss of information likely has continued, and worsened, with perverse outcomes. This suggests a potential gain from reinforcing environmental health risk information.

Further, due to the ongoing installation of new private wells, at least one-third of wells in Bangladesh are untested for arsenic (WASH Research Team, 2008; George *et al.*, 2002; Schoenfeld, 2005, records cases of households staying at untested wells and households switching to untested wells, again suggesting a gain from further well testing). Thus, a significant fraction of the rural population is potentially being exposed to risks of arsenic-induced illnesses. As many health risks from arsenic are higher if the arsenic exposure is longer, our results suggest the ongoing lack of well testing is missing an opportunity to help such vulnerable populations.

References

Ahmed, M.F., S. Ahuja, M. Alauddin, S.J. Hug, J.R. Lloyd, A. Pfaff, T. Pichler, C. Saltikov, M. Stute, and A. van Geen (2006), 'Ensuring safe drinking water in Bangladesh', *Science* **314**: 1687–1688.

Alstead, M., M. Campsmith, S.S. Halley, K. Hartfield, G. Goldbaum, and R.W. Wood (1999), 'Developing, implementing and evaluating a condom promotion program targeting sexually active adolescents', *AIDS Education and Prevention* **11**: 497–512.

Argos, M., T. Kalra, P.J. Rathouz, *et al.* (2010), 'A prospective cohort study of arsenic exposure from drinking water and all-cause and chronic disease mortality in Bangladesh', *The Lancet* **6736**: 60481–60483.

Beardslee, W.R., E.J. Wright, T.G. Gladstone, and P. Forbes (2007), 'Long-term effects from a randomized trial of two public health preventive interventions for parental depression', *Journal of Family Psychology* **21**: 703–713.

Black, M.E., J. Yamada, and V. Mann (2002), 'A systematic literature review of the effectiveness of community-based strategies to increase cervical cancer screening', *Canadian Journal of Public Health* **9**: 386–393.

we look for a link to the 2003–2005 switching decisions. In our sample, 689 households at unsafe wells consistently report 2003–2005 switching and correctly recall arsenic status in 2005. Of those who did switch away from their unsafe wells, 2 per cent had changed safety perception by 2008. Yet of those who did not switch from their unsafe wells in 2003–2005, 14 per cent stated in 2008 that their well was safe. We find a negative coefficient for 2003–2005 switching in a regression explaining the shifts in safety perception but it is not distinct from zero at a 10 per cent level ($p < 0.15$).

British Geological Survey (2001), British Geological Survey Report WC/00/19. Keyworth: BGS.

Caldwell, B.K., J.C. Caldwell, S.N. Mitra, and W. Smith (2003), 'Tubewells and arsenic in Bangladesh: challenging a public health success story', *International Journal of Population Geography* **9**: 23–38.

Chen, Y., A. van Geen, J.H. Graziano, A. Pfaff, M. Madajewicz, F. Parvez, I. Hussain, V. Slavkovich, and H. Ahsan (2007), 'Reduction in urinary arsenic levels in response to arsenic mitigation efforts in Araihazar, Bangladesh', *Environmental Health Perspectives* **115**: 917–923.

Chen Y., J.H. Graziano, F. Parvez, *et al.* (2011), 'Arsenic exposure from drinking water and cardiovascular disease mortality: a prospective cohort study in Bangladesh', *British Medical Journal* **342**: d243.

Downs, J.S., G. Loewenstein, and J. Wisdom (2009), 'Strategies for promoting healthier food choices', *American Economic Review: Papers and Proceedings* **99**: 159–164.

Duflo, E., P. Dupas, M. Kremer, and S. Sinei (2006), 'Education and HIV/AIDS prevention: evidence from a randomized evaluation in Western Kenya', World Bank Policy Research Working Paper No. WPS4042, Washington, DC.

Dupas, P. (2010), 'Do teenagers respond to HIV risk information? Evidence from a field experiment in Kenya', *American Economic Journal: Applied Economics* **3**: 1–34.

Farrelly, M.C., C.G. Healton, K.C. Davis, P. Messeri, J.C. Hersey, and M.L. Haviland (2002), 'Getting to the truth: evaluating national tobacco counter-marketing campaigns', *America Journal of Public Health* **92**: 901–907.

Fehr, E. and U. Fischbacher (2003), 'The nature of human altruism', *Nature* **425**: 785–791.

Fender, G.R., A. Prentice, T. Gorst, R.M. Nixon, S.W. Duffy, N.E. Day, and S.K. Smith (1999), 'Randomized controlled trial of educational package on management of menorrhagia in primary care: the Anglia menorrhagia education study', *British Medical Journal* **318**: 1246–1250.

Fewtrell, L., R.B. Kaufmann, D. Kay, W. Enanoria, L. Haller, and J.M. Colford Jr. (2005), 'Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis', *The Lancet Infectious Disease* **5**: 42–52.

Freeman III, A.M. (1993), *The Measurement of Environmental and Resource Values: Theory and Methods*, Washington, DC: Resources for the Future.

George, C.M., J.H. Graziano, J.L. Mey, and A. van Geen (2012), 'Impact on arsenic exposure of a growing proportion of untested wells in Bangladesh', *Environmental Health* **11**: 7; doi: 10.1186/1476-069X-11-7.

Grossman, M. (1972), 'On the concept of health capital and the demand for health', *Journal of Political Economy* **80**: 223–255.

Hanchett, S., Q. Nahar, A. van Agthoven, C. Geers, and F.J. Rezvi (2002), 'Increasing awareness of arsenic in Bangladesh: lessons from a public education campaign', *Health Policy and Planning* **17**: 393–401.

Harnack, L. and S. French (2008), 'Effect of point-of-purchase calorie labeling on restaurant and cafeteria food choices: a review of the literature', *International Journal of Behavioral Nutrition and Physical Activity* **5**: 51–56.

Jalan, J. and E. Somanathan (2008), 'The importance of being informed: experimental evidence on demand for environmental quality', *Journal of Development Economics* **87**: 14–28.

Johnston, R.B., A. Hanchett, and M.H. Khan (2010), 'The socioeconomics of arsenic removal', *Nature Geoscience* **3**: 2–3.

Jones, E., S. Schulz-Hardt, D. Frey, and N. Thelen (2001), 'Confirmation bias in sequential information search after preliminary decisions: an expansion of dissonance theoretical research on selective exposure to information', *Journal of Personality and Social Psychology* **80**: 557–571.

Karlan, D., M. McConnell, S. Mullainathan, and J. Zinman (2010), 'Getting to the top of mind: how reminders increase saving', NBER Working Paper No. 16205, Cambridge, MA.

Kennedy, C.E., A.M. Medley, M.D. Sweat, and K.R. O'Reilly (2010), 'Behavioral interventions for HIV positive prevention in developing countries: a systematic review and meta-analysis', *Bulletin of the World Health Organisation* **88**: 615–623.

Madajewicz, M.A., A. Pfaff, A. van Geen, J. Graziano, I. Hussein, H. Momotaj, R. Sylvi, and H. Ahsan (2007), 'Can information alone change behavior? Response to arsenic contamination of groundwater in Bangladesh', *Journal of Development Economics* **84**: 731–754.

Miguel, E. and M. Kremer (2004), 'Worms: identifying impacts on education and health in the presence of treatment externalities', *Econometrica* **72**: 159–217.

Munshi, K. and J. Myaux (2006), 'Social norms and fertility transition', *Journal of Development Economics* **80**: 1–38.

Nickerson, R.S. (1998), 'Confirmation bias: a ubiquitous phenomenon in many guises', *Review of General Psychology* **2**: 175–220.

Nyström, L., I. Andersson, N. Bjurstam, J. Frisell, B. Nordenskjöld, and L.E. Rutqvist (2002), 'Long-term effects of mammography screening: updated overview of the Swedish randomised trials', *The Lancet* **359**: 909–919.

Opar, A., A. Pfaff, A.A. Seddique, K.M. Ahmed, J.H. Graziano, and A. van Geen (2005), 'Responses of 6500 households to arsenic mitigation in Araihazar, Bangladesh', *Health and Place* **13**: 164–172.

Ozminkowski, R.J., D. Ling, R.Z. Goetzel, J.A. Bruno, K.R. Rutter, F. Isaac, and S. Wang (2002), 'Long-term impact of Johnson & Johnson's Health & Wellness Program on health care utilization and expenditures', *Journal of Occupational & Environmental Medicine* **44**: 21–29.

Pattanayak, S.K. and A. Pfaff (2009), 'Behavior, environment and health in developing countries: evaluation and valuation', *Annual Review of Resource Economics* **1**: 183–217.

Pattanayak, S.K., C. Poulos, J.C. Yang, and S. Patil (2010), 'How valuable are environmental health interventions? Evaluation of water and sanitation programmes in India', *Bulletin of the World Health Organisation* **88**: 535–542.

Preston, S.H. (1996), 'American longevity: past, present and future', Center for Policy Research Paper No. 36, Syracuse University, New York.

Schoenfeld, A. (2005), 'Area, village, and household response to arsenic testing and labeling of tubewells in Araihazar, Bangladesh', Master's thesis in Earth and Environmental Science Journalism, Columbia University.

Shimshack, J., M. Ward, and T. Beatty (2007), 'Mercury advisories: information, education, and fish consumption', *Journal of Environmental Economics and Management* **53**: 158–179.

Siegel, M. and L. Biener (2000), 'The impact of an antismoking media campaign on progression to established smoking: results from a longitudinal youth study', *American Journal of Public Health* **90**: 380–386.

Sircar, B.K., P.G. Sengupta, S.K. Mondal, D.N. Gupta, N.C. Saha, S. Ghosh, B.C. Deb, and S.C. Pal (1987), 'Effect of handwashing on the incidence of diarrhoea in a Calcutta slum', *Journal of Diarrhoeal Diseases Research* **5**: 112–114.

Siriwardena, A.N., A. Rashid, M.R.D. Johnson, and M.E. Dewey (2002), 'Cluster randomised controlled trial of an educational outreach visit to improve influenza and pneumococacal immunisation rates in primary care', *British Journal of General Practice* **52**: 735–740.

Stanton, B.F. and J.D. Clements (1987), ‘An educational intervention for altering water-sanitation behaviors to reduce childhood diarrhea in urban Bangladesh II: a randomized trial to assess the impact of the intervention on hygienic behaviors and rates of diarrhea’, *American Journal of Epidemiology* **125**: 292–301.

Thornton, R.L. (2008), ‘The demand for, and impact of, learning HIV status’, *American Economic Review* **98**: 1829–1863.

van Geen, A., H. Ahsan, A.H. Horneman, *et al.* (2002), ‘Promotion of well-switching to mitigate the current arsenic crisis in Bangladesh’, *Bulletin of the World Health Organisation* **83**: 49–57.

van Geen, A., Y. Zheng, R. Veersteeg, *et al.* (2003), ‘Spatial variability of arsenic in 6000 tube wells in a 25 km^2 area of Bangladesh’, *Water Resources Research* **39**: HWC 3-1–HWC 3-16.

van Geen, A., M. Trevisani, J. Immel, M. Jakariya, N. Osman, Z. Cheng, A. Gelman, and K.M. Ahmed (2006), ‘Targeting low-arsenic groundwater with mobile-phone technology in Araihazar, Bangladesh’, *Journal of Health, Population and Nutrition* **24**: 282–297.

WASH Research Team (2008), *WASH Programme of BRAC: Towards Attaining the MDG Targets: Baseline Findings*, Dhaka: BRAC Publications.

Wisdom, J., J. Downs, and G. Loewenstein (2010), ‘Promoting healthy choices: information versus convenience’, *American Economic Journal: Applied Economics* **2**: 164–178.

World Bank (2005), ‘Towards a more effective operational response: arsenic contamination of groundwater in South and East Asian Countries 1’, Policy Report No. 31303, World Bank Publications, Washington, DC.