POLICY RESEARCH WORKING PAPER 1568

Determinants of Diarrheal Disease in Jakarta

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Is there defensive behavior to prevent diseases such as diarrhea in Jakarta? Yes. And evidence suggests that individual defensive behavior is influenced by exposure to contamination and income and education — as expected. So, given the opportunity and knowledge, individuals try to modify the effect of contamination on the incidence of diarrhea. But that incidence is also affected by the water company and its problems, factors that lie outside the realm of the household.

The World Bank
Policy Research Department
Public Economics Division
January 1996

Summary findings

Alberini, Eskeland, Krupnick, and McGranahan develop and estimate a model of household defensive behavior and illness. Using cross-section data from a household survey in Jakarta, they observe defensive behavior (washing hands after using the toilet) consistent with expectations: Defensive effort intensifies with exposure to contamination, and with income and education.

Variables associated with the cost of defensive behavior — such as interruptions in the water supply — reduce defensive behavior.

The data suggest that wealthier households are no less vulnerable to illness. The water sources that supply the wealthy (the water company and private wells) are disrupted more often, interfering with their defensive behavior.

There is also evidence, although weak, to support findings by van der Slice and Briscoe (1993): that pathogens originating within a household are less harmful to household members than are pathogens originating from other households.

Given the opportunity and knowledge, individuals try to modify the effect of contamination on the incidence of diarrhea. But diarrhea's incidence is also affected by decisions and problems outside the realm of the household, including the performance of the water company.

This paper — a product of the Public Economics Division, Policy Research Department — is part of a larger effort in the department to analyze pollution control in developing countries. The study was funded by the Bank's Research Support Budget under the research project "Pollution and the Choice of Policy Instruments in Developing Countries" (RPO 676-48). Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Cynthia Bernardo, room N10-053, telephone 202-473-7699, fax 202-522-1154, Internet address cbernardo@worldbank.org. January 1996. (33 pages)

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by

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We gratefully acknowledge, without implication, helpful comments from John Briscoe, Carl Bartone and Mariam Claeson at the World Bank.

1. Introduction

A growing body of literature has explored the link between health and environmental quality in developing countries. Attention has been particularly focused on diarrhea because of the mortality and morbidity risks it poses to infants and young children. Based on losses in terms of disability-adjusted life years, the World Development Report (1993) estimates that diarrheal disease is the third most burdensome illness among children in the 0 to 5 years age bracket (after perinatal and acute respiratory illness). Using 1990 data, Murray and Lopez (1994) estimate that about 3 million children die every year of diarrheal disease.

Diarrheal disease is usually attributed to ingestion of water or foods that are contaminated with fecal coliforms or other pathogens, or to fecal-oral contamination. Its causes may, therefore, involve the individual household, the public sector as a provider of private goods and services, such as water supply and sanitation, and as a provider of public goods such as pest control programs or improved surface water quality.[1]

Accordingly, understanding the links between the incidence and severity of diarrheal illness and alternative interventions is a necessary input into the government's decisionmaking. However, there is currently much uncertainty about the most appropriate policies in the context of low-income urban environments. The debate can be described in terms of hypotheses about whether the decisive factors are economic/behavioral or engineering/infrastructure. The economic/behavioral perspective emphasizes attention to and interpretation of household behavior, and the relationship between the appropriate interventions and the resources and preferences of the households. The technical perspective emphasizes more strongly the need to provide households with a plentiful and reliable supply of uncontaminated water and adequate sanitation services.

[1] There is often a public good aspect to the quality of a private good. An example is the quality of the water purchased from a water company, since it may be very costly for individuals to choose their own level of quality.

These factors are often tightly intertwined. One might find, for instance, that diarrhea incidence is low in a city with contaminated water, *because* households are careful in their personal hygiene, and boil water before drinking. In such a setting, an engineering intervention, such as improvement in water quality, could prove ineffective in lowering diarrhea rates *because* of the importance of behavioral factors. Intervention might still be justified, however, depending on the costs imposed by the defensive behavior.

Ascertaining exposure to contamination has proved to be very challenging, due to the variability of contamination in time and space and to the number of possible contamination routes. Briscoe (1984), for instance, emphasizes the complexities in empirical investigations when there may be interdependencies and "threshold-saturation" effects in transmission routes. Esrey et al. (1985, 1991) suggest that public interventions may exhibit varying levels of effectiveness in controlling the transmission of diarrheal disease, and that a plentiful water supply and/or adequate sanitation appear to have a greater impact on diarrheal disease than improvements in water quality. The World Bank (1992) provides a similar message, but adds that for certain types of improvements in sanitation (those removing excreta from the neighborhood), benefits will be reaped mainly at the neighborhood level, rather than by the household itself. Martines et al. (1991) conclude that effectiveness in lowering disease rates, and particularly the severe and mortal cases, depends on broader preventive strategies, including water supply and sanitation, nutrition and education programs. Using clinical data, Baltazar et al. (1988) find evidence that adequate sanitation practices reduce the incidence of diarrheal illness.

This paper reports on the results of an empirical investigation of the effects of engineering variables (water supply, proxies for the risk of contamination) and individual behavior on diarrheal disease in Jakarta. The data source is a major household survey conducted by the Stockholm Environment Institute in 1991 (McGranahan, 1994; Surjadi, 1993). The survey elicited information on the households' socio-economic and demographic circumstances, their local environmental conditions and practices, and the health of those household members (the mother and children under six) most likely to be adversely affected by the household environment. Diarrhea was one of the health conditions monitored, and many of the environmental variables were relevant to the fecal-oral routes through which diarrheal diseases typically spread. Complementing the questionnaire surveys, water samples from a subset of 201 households were tested for fecal contamination.

We find that water *quantity* -- in the sense of reliable, uninterrupted supply -- matters more than quality in preventing diarrheal illness in Jakarta, and that other engineering/infrastructure variables are significantly associated with illness and preventive behavior. Among our most surprising results is that wealthier households are vulnerable to illness. We find evidence that they are more exposed to interruptions in the supply of water, due to their choice of water source, and that interruptions interfere with defensive behavior.

This paper is organized as follows: Section 2 provides the analytical framework and econometric model, Section 3 describes the data, and Section 4 reports estimation strategy and results. Section 5 concludes.

2. Modeling The Determinants Of Diarrheal Disease

A Model of Defensive Activities and Illness

This section presents a simple model of illness and household defensive behavior in response to the threat of contamination based on Harrington, Krupnick and Spofford (1989). Let U denote the household utility level, which depends on the household's aggregate consumption, X, leisure, L, and time spent ill, S. Time spent ill, S, is, in turn, a function of the potential for contamination, C, and the household's defensive behavior, which we express as the time, T_d, the household spends on defensive activities. The household maximizes utility, $(X,L,S(T_d,C))$, subject to the budget constraint:

(1) $$y + w(\overline{T} - L - T_d - S(T_d, C)) = X + p_d T_d$$

where y is non-labor income, $\overline{T}$ the total time available to the household, w the wage rate, and p_d the out-of-pocket cost of defensive behavior (*i.e.*, the cost of fuel used for boiling water, the cost of purchasing additional water or soap for washing hands, etc.).[2] The opportunity costs of defensive behavior (foregone earnings and leisure) are included in the right-hand side of the budget equation.

The first-order conditions for optimizing the lagrangean:

(2) $$(X, L, S(T_d, C)) + \lambda[y + w(\overline{T} - L - T_d - S(T_d, C)) - X - p_d T_d)]$$

with respect to X, L, and T_d are easily shown to be:

(3) $${}_X - \lambda = 0$$

(4) $${}_L - \lambda w = 0$$

(5) $$U_S \frac{\partial S}{\partial T_d} - \lambda\left(w \frac{\partial S}{\partial T_d} + p_d\right) = 0\,.$$

Under regularity assumptions, an interior solution exists if the household perceives being adversely affected by disease (${}_S < 0$) and deems the defensive behavior to be worthwhile ($\frac{\partial S}{\partial T_d} < 0$). Essentially, the household engages in defensive activities (thus incurring expenses and investing time) to the point that the marginal utility from the reduction in illness resulting from the defensive activities equals the marginal disutility of the foregone consumption and leisure. The optimal defensive behavior derived from the first-order conditions (3)-(5):

(6) $$T_d^* = T_d^*(w, p_d, y, C),$$

is, therefore, a function of the wage rate, w, of non-labor income, y, of the cost of the defensive activity, p_d, and of the threat of contamination, C. On inserting the optimal T_d^* into the dose-response function S, we obtain:

(7) $$S = S(T_d^*, C)\,.$$

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[2] The price of consumption goods is normalized to one.

We estimate equations (6) and (7) for Jakarta using household-level data. As shown below, for both equations we offer specifications based on binary observed dependent variables, because of the nature of behavior (*e.g.*, households either do or do not boil water for drinking) or lack of more precise information (we know whether or not household members experience diarrheal illness, but not for how long). We include factors appearing in (6) and (7) directly in the right-hand side, when they are available. In their absence, we resort to proxies for them.

The contamination threat variables pose a special challenge. Direct information -- the count of fecal coliforms -- is available on source and boiled water quality (at least for a portion of the sample), but needs to be augmented to account for the contamination potential from other routes, such as fecal-oral contact, contamination inside and outside of the dwelling, contact of food with insects or other rodents that carry pathogens, and contaminated food prepared by persons other than the household members.

Even the available proxies for contamination, however, may turn out to be endogenous with defensive behavior, reflecting self-selection on the part of the respondents, rather than being measures of exogenous threats. In addition, we recognize that household members may be aware of other forms of contamination that are not observable to us. Unless accounted for and incorporated into an explicit simultaneous equations model, these unobservable sources of contagion result in biased estimates. The details of our econometric models for equations (6) and (7) are laid out in the next section.

Structure of the Econometric Model

Suppose that individuals engage in defensive behavior if the value taken by a random variable y_1^* is greater than zero. Let y_1^* be determined by individual/household characteristics (including the wage rate, non-labor income and the cost of defensive behavior) and risk factors known to the researcher (both sets of variables being summarized into a vector of regressors x_1), and perceived exposure to a risk factor for diarrheal disease, R^*:

(8) $$y_1^* = x_1\beta_1 + \gamma_1 R^* + \varepsilon ,$$

where ε is random error term and R^* is known to the subject but not to the researcher. It is assumed that a higher value of R^* implies a higher risk for diarrheal diseases, and thus results in a higher defensive effort. The coefficient γ_1 is thus assumed to be positive. Because observations on the dependent variable, y_1^*, are available only in a binary response format, model (8) is estimated using probit techniques.

Further assume that diarrheal disease is observed in a household when a second random variable, y_2^*, defined as:

(9) $$y_2^* = x_2\beta_2 + \gamma_2 R^* + \delta y_1^* + \eta$$

takes on a value greater than zero. Here x_2 is also a set of individual and household characteristics and sources of risk for diarrheal disease that are observable to the researcher. γ_2, the coefficient of sources of risk R^* not observable to the researcher is positive, implying that a higher-valued R^* increases the likelihood of contracting the illness. Diarrhea is controlled with the defensive behavior, y_1^*, so that the coefficient δ is negative. Equation (9) is also estimated using binary response techniques. The errors terms ε and η are assumed to be independent of each other.

Because the risk factor R^* is not known to the researcher, it cannot be treated as a regressor in the equations for defensive behavior and diarrheal illness resulting from (8) and (9). It will thus be absorbed into the error terms $\nu_1 = \gamma_1 R^* + \varepsilon$ and $\nu_2 = \gamma_2 R^* + \eta$. A probit regression of observed defensive behavior on the selected regressors yields consistent estimates, provided of course that x_1 is independent of the error ν_1. However, a probit regression of diarrheal illness on individual characteristics and defensive behavior yields inconsistent estimates because the "hidden" risk factor has introduced correlation between one of the regressors -- defensive behavior -- and the error term ν_2 in the illness equation. The binary dependent variable counterparts of equations (8) and (9) must, therefore, be estimated as a system of simultaneous equations.[3]

Equation (8) is, essentially, already expressed in reduced form, in the sense that it contains only exogenous regressors. Substituting equation (8) into (9) we obtain a second reduced-form equation in which defensive behavior is eliminated from the regressors and diarrheal disease depends only on individual or household characteristics and unobservable risk:

(10) $$y_2^* = x_2\beta_2 + x_1(\delta\beta_1) + [(\delta\gamma_1 + \gamma_2)R^* + (\delta\varepsilon + \eta)] \ .$$

The error term of equation (10) (in brackets) is easily shown to be correlated with the error term of the first equation, $\nu_1 = \gamma_1 R^* + \varepsilon$. The covariance between the error terms of the reduced-form equations (8) and (10) is equal to:

(11) $$(\delta\gamma_1 + \gamma_2)\gamma_1 \cdot Var(R^*) + \delta \cdot \sigma_\varepsilon^2 .$$

Since δ is negative, the sign of covariance (11) depends on the sign of $(\delta\gamma_1 + \gamma_2)\gamma_1$ and on the relative magnitude of $Var(R^*)$ and σ_ε^2. The quantity $(\delta\gamma_1 + \gamma_2)$ gives the net effect on illness of a change in the unobservable risk (*i.e.*, after the individual's defensive actions). If $(\delta\gamma_1 + \gamma_2)<0$, each increase in unobserved risk unleashes a defensive response strong enough *and* effective enough to produce a net *reduction* in the likelihood of contracting diarrhea. If $(\delta\gamma_1 + \gamma_2)=0$, the individual can just neutralize an increase in risk through enhanced defensive actions.[4] Finally, if $(\delta\gamma_1 + \gamma_2) > 0$ an increase in unobserved risk results in a higher likelihood of contracting illness. It is easily shown that $(\delta\gamma_1 + \gamma_2)<0$ results in covariance (11) also being

[3] Only if $\gamma_1 = 0$ is it legitimate to fit the probit equation for diarrheal disease separately without incurring inconsistent estimates.

[4] Two important special cases are (i) $\gamma_1 = 0$ but $\delta \neq 0$, and (ii) $\delta = 0$ (for any value of γ_1). Under case (i), people are not aware that washing hands serves as a means of reducing the risk of contagion. They will not, therefore, intensify their defensive behavior in the face of an increase in the risk of contamination. The covariance, (11), is easily shown to be negative. Under case (ii), the defensive behavior is completely ineffective in reducing the likelihood of diarrheal disease. The covariance, (11), between the error terms of the reduced-form equations is positive (zero if $\gamma_1 = 0$).

negative. If $(\delta\gamma_1 + \gamma_2)$ is positive the sign of covariance (11) is undetermined (*i.e.*, a negative covariance does not necessarily imply that $(\delta\gamma_1 + \gamma_2) < 0$).

While the diarrhea equation can be separately estimated by probit techniques as long as it is expressed in its reduced form (10), we estimate diarrheal illness jointly with defensive behavior from the reduced form to fully capture the relationship between defensive actions and illness. We assume that the errors of the reduced-form equations (which incorporate the unobserved risk) are jointly normally distributed. The resulting joint model for the observables is a bivariate probit with sets of regressors x_1 in the defensive behavior equation, and x_1 and x_2 in the illness equation.[5] The unobserved risk R^* is absorbed into the error terms, but its contribution to both defensive behavior and illness is now adequately accounted for by allowing those error terms to be correlated.

We note that the parameters appearing in equations (8) and (9) cannot all be separately identified. As with standard probit equations, our bivariate probit routine estimates the *ratios* $\widetilde{\beta}_1 = \beta_1 / \sigma_1$ and $\widetilde{\beta}_2 = \beta_2 / \sigma_2$, where σ_1 and σ_2 denote the standard deviations of the reduced-form error terms. σ_1 and σ_2 cannot be identified, nor can the two γs and δ, not even for non-overlapping x_1 and x_2.

3. The Data

Survey Instrument and Sampling Frame

The survey questionnaire contained nine modules, covering demographics, health status and history, and a host of risk factors for gastro-intestinal and respiratory disease. The variables used in this paper are drawn primarily from the water, sanitation, and health modules but also include selected variables taken from other modules. The water module had questions on the principal and secondary sources of drinking water, the sources of

[5] See Greene (1993) for details on bivariate probit models.

water used for other purposes, sharing patterns, the boiling of drinking water, interruptions in the water supply, and storage of water supplies.[6]

The sanitation module asked about access to private toilet facilities, the type of toilets, sharing patterns, use of public toilets by household members, and open defecation practices in the neighborhood. The respondent was also asked open-ended questions about their own hand washing practices, with the responses coded according to whether they mentioned handwashing (regularly) before preparing food or after using the toilet.

The health module was designed to collect information on up to three children under six (in the three households with more than three children under six, the oldest children were not included). The respondents were asked to describe the symptoms of any illnesses the children had had in the last two weeks, and, following prompts by the enumerators, these symptoms were coded according to the International Classification of Primary Care (ICPC). Further details on the more severe diarrheal episodes (involving at least three loose stools a day), such as duration and evidence of dehydration, were also collected.

Other variables were drawn from the household composition, pest and observation modules. The module on the household composition included questions on the age, sex, and responsibilities of the household members, and the education, place of origin, and length of residence in Jakarta of the head of the household and the principal homemaker. The module on wealth included questions on appliance and vehicle ownership, as well as the actual or imputed rent of the residence and the tenure of the dwelling and land. As part of the observation module, the presence of a washbasin in the vicinity of the toilet was noted.

The sampling procedure was designed to provide a sample of at least 1,000 households from within the special district (DKI) of Jakarta, with all households of fixed

[6] More details about the survey are available in Surjadi (1993). McGranahan (1994) and McGranahan and Songsore (1994) compare findings from Jakarta, Accra and Sao Paulo.

abode having approximately the same likelihood of being selected.[7] Near completed records, including health information, are available for 1037 of the 1055 households.

Of these 1037 households, 488 households included children under 6 years old, for a total of 622 "young" children. In addition, 201 of the households surveyed provided samples of water from their primary source (the tap, a privately owned well, or the appropriate container) and samples of boiled water prepared for drinking.

Illness Data

Two classification criteria were used for diarrheal disease, a more rigorous and a looser definition of the illness. A household member reporting at least three loose stools per day was assigned the rigorous definition. Only 3.3% percent of the homemakers (3.6% of the homemakers with young children) and 3.7% of the young children had such a case of diarrhea.[8] With so few cases, we turned to the looser definition for the analysis.

The looser definition differs for children and the homemaker. For children, it involved the homemaker reporting that her child had diarrhea (including episodes less serious than three or more loose stools per day). For adults, it includes any symptoms of gastrointestinal distress during the recall period, including diarrhea, a stomach ache, blood in the stools, or vomiting. About 5.6% of the young children were reported by their mothers to have contracted diarrhea in the last two weeks. Somewhat surprising was the finding that mothers reported a slightly higher incidence of this illness in the same period: 10.9% of the mothers of young children and 10% of all principal homemakers reported that they had diarrhea or other gastro-intestinal disruption

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[7] First, 211 census blocks were chosen through systematic random sampling from the 6,565 census blocks in all of DKI Jakarta. Then systematic random sampling was employed again to obtain an average of five completed and inspected survey forms from each block. Double data entry was employed.

[8] The principal homemakers targeted by the study were predominantly (95%) women. Their ages ranged between 17 and 71 years (the average was 39 and the median 37).

themselves. Among the 488 mothers of young children, only 8 (1.6%) had had an illness concurrently with one of their children.[9] Interestingly, among the households with young children, there were no households in which more than one child was ill at the same time over the recall period. In 135 households (13% of the sample) at least one person (the mother and/or one of the children) had experienced an episode of diarrhea in the previous two weeks.

Water Supply Data

The government-piped drinking-water supply system (PAM) services a small portion of respondents directly. Only 18% of respondents had piped water connections in their homes. A further 22% had to buy drinking water from water vendors, and 4% from public hydrants, implying that about 44% of households obtain drinking water at least indirectly from the PAM system. (Public hydrants are constructed by the government, but operated by private managers who sell the water to vendors and consumers). Despite Jakarta's size and density, about 51% used water from wells. About 5% used other sources for drinking water, including bottled water.

As illustrated in Table 1, the principal difference in the drinking water source of poor and wealthy households is that the poor often use vendors or public hydrants, and rarely have household connections, while with wealthy households the situation is reversed. On the other hand, a large share of households in every wealth quintile use well water. This reflects the importance of location, and more specifically ground water salination, in determining drinking water sources.[10]

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[9] Unfortunately, no information was available as to whether other household members had also experienced diarrhea during the recall period.

[10] Some 40% of the sample lived in areas of Jakarta where the ground water is considered salinated. For wealthier households, salinated groundwater generally means having a piped water connection rather than a well, while for poor households it more typically means buying drinking water from a water vendor, but continuing to use well water for other purposes.

Table 1. Source of drinking water by wealth quintile.

	poorest 20%	lower middle 20%	middle 20%	upper middle 20%	wealthiest 20%	row total
PAM	13	20	27	44	78	182
private well	77	117	109	111	86	500
mineral water	0	0	0	2	13	15
hydrant	13	10	19	4	0	46
vendor	66	40	42	44	33	225
other source away from home	23	10	6	1	2	42
public well	12	10	3	2	0	27
column total	204	207	206	208	212	1037

Table 2. Water Supply Interruptions by Source of Drinking Water.

Source of Drinking Water	Percent of Households Experiencing Interruptions
PAM	40.7
Private Well	48.2
Mineral Water	13.3
Hydrant	37.0
Other Source Away from Home	31.0
Vendor	12.0

Table 3. Frequency of Households Served and Water Supply Interruptions by District and Water Source.

	North Jakarta	West Jakarta	Central Jakarta	East Jakarta	South Jakarta
PAM	49 (36.73%)	34 (52.94%)	58 (37.93%)	16 (43.75%)	25 (36.00%)
Private Well	5 (0%)	56 (42.86%)	27 (11.11%)	200 (52.50%)	212 (51.42%)
Mineral Water	2 (0%)	5 (0%)	2 (0%)	4 (50.00%)	2 (0%)
Hydrant	29 (58.62%)	7 (57.14%)	4 (50.00%)	3 (33.33%)	3 (20.00%)
Other Source Away from Home	8 (37.50%)	11 (27.27%)	8 (25.00%)	10 (40.00%)	5 (20.00%)
Vendor	58 (27.59%)	98 (1.02%)	50 (4.00%)	16 (43.75%)	3 (33.33%)
Public Well	--	13 (46.15%)	3 (0%)	6 (16.67%)	5 (60.00%)
Percent of households experiencing interruptions	35.75%	25.00%	19.74%	49.80%	49.02%

The numbers in parentheses are the fractions of households served that experience regular interruptions in the delivery of water.

As many as 38 percent of the households surveyed experience regular interruptions in the delivery of water, all of them concentrated in the summer. As Table 2 shows, households served by PAM experience water supply interruptions no less frequently than households served by other sources. Households supplied by vendors, however, fare comparatively well, suggesting that vendors might fulfill the role of water supply stabilizers in dry times. Table 3 breaks down the households by their source of water and area of residence and gives the fraction of the households that experience supply interruptions, showing that the frequency of interruptions also varies with the area of the city the household resides in.[11]

Water Quality

About 60% of the samples of source water (*e.g.*, at the tap, for those households with a connection) were found to be contaminated with fecal coliforms, with over a third of the samples having counts greater than 10 per 100 ml of water. The distribution of the source water test results is shown in Figure 1.

Samples of water from the piped water containers were often found to be more contaminated than those taken from wells. Further analysis indicated that households supplied directly or indirectly by PAM in North Jakarta have the highest levels of water contamination, whereas private well water in East Jakarta has the lowest levels of contamination. It is interesting to note that prevailing interruptions in the water supply do not appear to be associated with higher contamination.[12]

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[11] Several studies report on the water supply system and water demand in Jakarta. Lovei and Whittington (1993) report that poorer households who do not have PAM connections pay higher unit prices for water, which they purchase from vendors or hydrant operators. They consume less water, but typically have higher water bills. Lovei and Whittington argue that the slow expansion of the utility's connections reflects the current incentive structure and results in rent-seeking on the supply side. Crane (1994) analyses the effects of a liberalization policy that allows households with connections to sell water, and finds that benefits accrue to poorer households, mainly in the form of lower unit prices (if water was earlier purchased from vendors) and time costs (if water was earlier purchased from hydrants).

[12] Interruptions in the service should not result in increased contamination if the water to be delivered is taken from an uncontaminated spring or reservoir, has been treated properly by a treatment plant, and the pipes are in good condition and free from leaks and corrosion. When the service is interrupted, however,

Figure 1

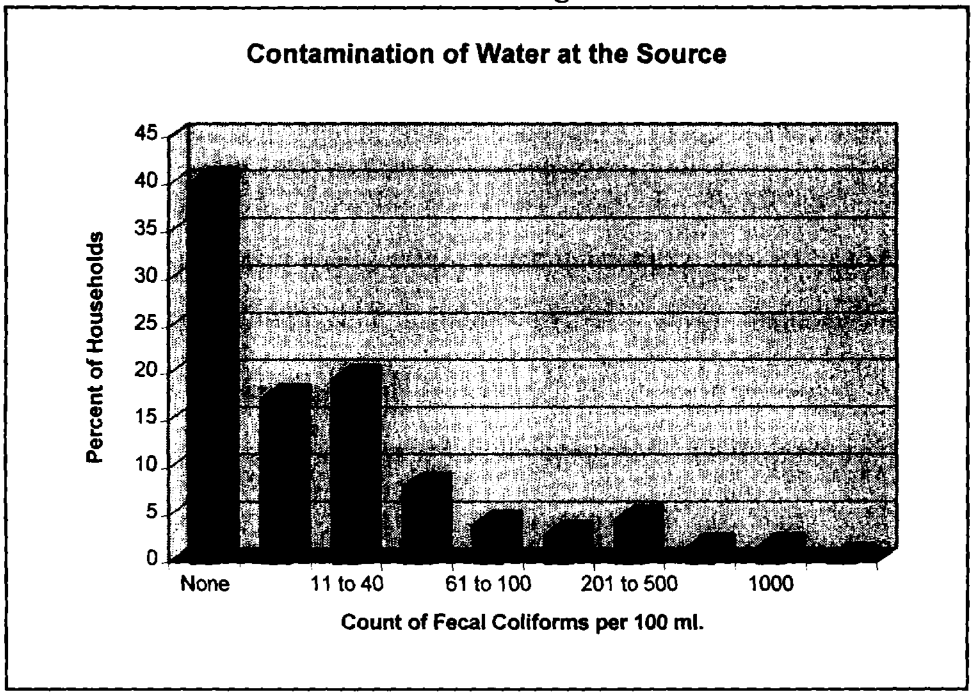
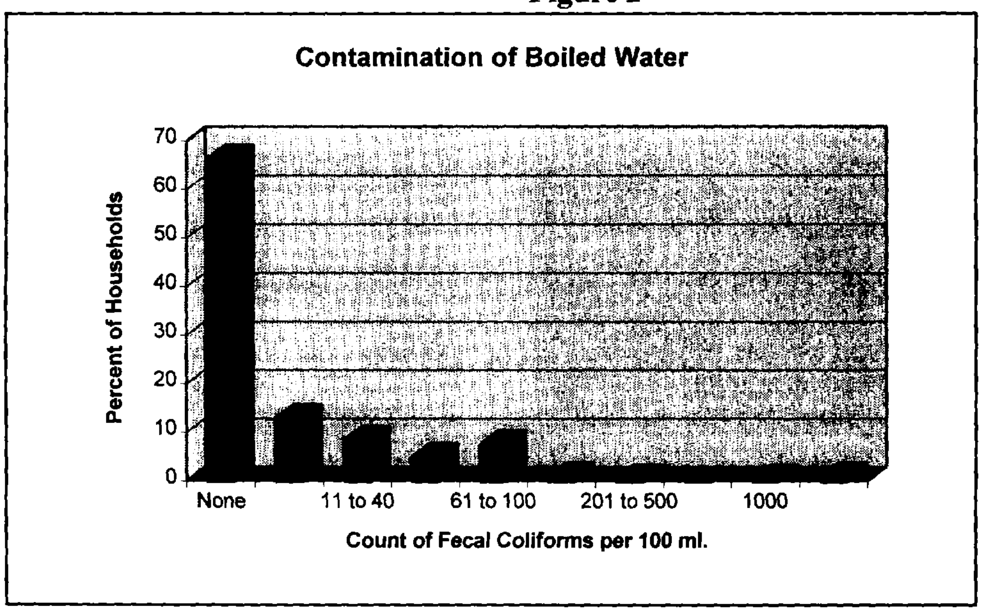


Figure 2



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the ensuing fall in pressure in the pipes may result in contaminants from the soil surrounding the pipes or a nearby water table leaching into corroded pipes. It is generally believed that in developing countries water pipes are often in poor condition. Hardoy, Mitlin and Satterthwaite (1994) suggest that in developing countries the losses due to leaks may be as large as 60% of the total volume of water (for comparison, the typical figure for the U.S. or Britain is only about 12%).

The dangers of contaminated water are mitigated by the fact that virtually all households boil their drinking water. It is reasonable to expect boiled drinking water to be free of pathogenic germs. Yet in this study it was found that 68 out of 200 boiled drinking-water samples (34%) contained fecal coliform at the time of drinking, as is shown in Figure 2. About 22 percent of the samples of boiled water were found to have counts of fecal coliforms greater than 10. This may be due to re-contamination in the household: the boiled water is often stored for some time before drinking. Alternatively, the water heating could be insufficient. Further analysis showed that contamination after the water was boiled was associated with contamination at the source, the absence of a hand washing basin in the lavatory (suggesting a link with hygiene practices), using public toilets, flies in the toilet area and with the district of residence.

Defensive Behavior

Ninety-nine percent of the respondents reported boiling their drinking water. Since virtually all households boil their water prior to consumption, we turn to washing hands as the defensive activity we wish to model jointly with diarrheal illness. Sixty-three percent of the respondents reported washing hands after using the toilet. In looking for determinants of defensive behavior, we note that the fraction of respondents who wash hands increases steadily with respondent's income *only* within households who do *not* experience water supply interruptions. Within households who *do* experience water supply interruptions the proportion of respondents who wash hands is approximately 35% regardless of income.

The presence/absence of a washbasin near the toilet -- an "engineering/infrastructure" variable -- is closely, but not perfectly, correlated with the washing hands behavior. As expected, higher-income and higher-education households are more likely to have a washbasin near the toilet.

4. Determinants Of Diarrheal Disease And Defensive Behavior

Water Contamination

Our first order of business is to identify variables that capture C, the variable representing the potential for contamination in equations (6) and (7). A natural candidate is, of course, drinking water (both at the source and boiled water prepared for drinking and stored in the home), which, as earlier discussed, is often found to be contaminated with fecal coliforms. As noted earlier, however tests for water contamination were performed only for a subset of 201 households.

Diarrheal disease is indeed twice as frequent in households whose source of water is contaminated with fecal coliforms than in households served by an uncontaminated supply of water.[13] This yields a significantly higher disease rate among the 175 households with water contaminated at the source than among the 26 households with no contamination at the source. However, fitting an explicit dose-response function (a probit regression of the diarrhea dummy on a constant and the log count of fecal coliforms in source water), yields no meaningful association.[14] Figure 3 shows why: within the households with contaminated water source the frequency of illness does not vary in a smooth and predictable fashion. We attribute this latter result to at least two factors. The first is the combination of relatively low general incidence of diarrheal disease and the small size of the sample for which contamination tests were performed (201 households). Second, the contamination levels given by water testing (the count of fecal coliforms in 100 ml. of water), are, at best, only a proxy for the dose of fecal coliforms ingested by individuals (VanDerslice and Briscoe, 1993).

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[13] Because we do not have sufficient information about the health status of members of the households other than the mother and children, and only one child is reported to have symptoms, we simply look at the presence of infection in the household and do not attempt to model in detail how the illness is spread within the household.

[14] The probit regression gives an intercept term of -1.2310 (t-statistic -7.57) and a slope of 0.0683 (t-statistic 1.279).

Surprisingly, households with contamination in their containers of *boiled* water have a slightly *lower* incidence of diarrhea than the others (11.9 percent versus 14.8 percent). The incidence of diarrheal illness is, however, not significantly different between the two groups. We may compare our findings to those of VanDerslice and Briscoe (1993), who suggest that pathogens contained in drinking water are less of a health threat if they are more likely to have originated from within the household than from other individual members. In our data, contamination in the container of boiled water is likely to have originated within the household, and was not found to be significantly associated with disease. Contamination of the water source (at the tap) was found significantly related to disease in one formulation, but not in another. These finding lend some support to the VanDerslice-Briscoe thesis, but this interpretation is subject to the limitations of our data.

In order to augment the sample size for our dose-response relationships, we used the coefficients of a regression of boiled water contamination and of a regression establishing the determinants of source contamination to form predictors for the count of fecal coliforms in boiled water and at the source for the 842 households for which water testing results are not available. The subsamples with measured and imputed counts of fecal coliforms were pooled to run probit dose-response relationships for diarrhea, but our efforts resulted in insignificant coefficients for the fecal coliform variables.[15]

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[15] This does not necessarily rule out a causal link between contamination of water and diarrheal illness. First of all, the quality of the prediction may be poor and result in a large variance of the prediction error, which in turn tends to give large standard errors and insignificant probit coefficients. Secondly, because only 13% of the households report experiencing diarrhea in the recall period, we may need a much larger sample size to ascertain this link. Last, but not least, the contamination levels we used may be a poor proxy for the actual doses of fecal coliforms ingested by the household members.

We also tried another way to form a prediction for the count of coliforms in boiled water. We used the average count of coliforms in their *kecamatan* for those households without water tests. However, this predictor was not found to be significantly associated with diarrheal disease.

Finally, we tried an alternative specification in which we replaced the count of fecal coliforms at the source with the predicted probability of contamination at the source, but once again failed to obtain a significant coefficient for the probability of contamination. We calculated the probability of fecal coliform contamination of the source as $\Phi(-0.1029 + 1.1574 * \text{nc\_publ} + 0.8092 * \text{w\_publ})$, where Φ is the standard

Since we fail to find a strong relationship between water quality and illness, we omit direct measures of water quality in our full, simultaneous-equations model below, and use water supply and interruption frequency dummies as proxies for quantity and quality of water and its accessibility to the household.

Other Measures of Contamination and Costs of Defensive Behavior

Because of the comprehensiveness of the Jakarta survey and the many routes of infection possible for diarrhea, there are literally hundreds of possible variables in the Jakarta dataset that could serve as proxies for contamination. We drew an initial set from the sanitation, waste disposal, socio-demographics, infrastructure/engineering and interviewer observation modules of the Jakarta survey. We ended up rejecting many of the potential proxy variables because they did not appear to be significantly related to diarrheal disease or defensive behavior (washing hands), not even under the most favorable circumstances (*i.e.*, as a single regressor against these dependent variables).

The variables that passed this screening included whether one or more household members frequent public toilets (positively associated with diarrheal illness),[16] and the perception of a problem with waste in the *neighborhood* (positively associated with washing hands).[17] Variables serving as proxies to the costs of averting behavior include the presence of a washbasin (negatively associated with diarrhea, positively associated

normal cumulative density function, nc_publ is a dummy variable that takes on a value of one if the household resides in North or Central Jakarta and is served by PAM, a vendor or a "hydrant," and w_publ is a dummy that takes on a value of one if the household is served by the same suppliers but resides in West Jakarta. We arrived at this specification after starting with a broader model that included dummies for the interactions between district and type of source, plus interruptions dummies. The initial model was simplified by deleting regressors that were not significant and consolidating variables that shared common coefficients. The dataset used for estimating this model was, of course, the group of households whose water was tested.

[16] Approximately 13% of the households have members who also frequent public toilets. Regular and occasional users of public toilet bemoan, in order of decreasing frequency, long lines, poor cleanliness, frequent breakdowns and inadequate flushing. About 33% of those interviewed report seeing people (almost exclusively children) defecating in the open in their neighborhood.

[17] We treated waste disposal variables as possible proxies for the presence of fecal material and/or other types of contamination in or around the dwelling, for which no direct observation is available.

with hand washing), interruptions in the water supply (positively associated with diarrhea, negatively associated with hand washing), and type of water source (public water negatively associated with hand washing).

Selection of Socio-demographic Variables

In the absence of information about the wage rate, we used household income (negatively associated with diarrhea, positively associated with hand washing), and education of the mother (positively associated with hand washing). We also retain the imputed rental value of the dwelling, which presumably captures quality and sanitary conditions of the dwelling and thus serves as a proxy for contamination, but is also highly correlated with income.[18] Descriptive statistics and correlations for selected variables are presented in tables 4 and 5.

Table 4. Descriptive Statistics for Selected Variables.

Variable	N	Mean	Std. Dev.	Min.	Max.
water supply interruptions	1037	0.39	0.49	0	1
young children in household	1037	0.62	0.77	0	4
washbasin	836	0.47	0.50	0	1
PAM	1037	0.18	0.38	0	1
private well	1037	0.48	0.50	0	1
hydrant	1037	0.04	0.21	0	1
vendor	1037	0.22	0.41	0	1
diarrhea in the household	1037	0.13	0.34	0	1
frequenting public toilets	1037	0.14	0.34	0	1
wash hands after toilet	1037	0.54	0.50	0	1
monthly household income (thou. of rupias)	1037	461	680	15	10000
problems with waste in the neighborhood	1046	0.44	0.50	0	1
mother's education[a]	818	11.5	6.4	0	24

[a] Indicator variable ranging from 0 (illiterate) to 24.

[18] Interviewers noticed damp walls or floors in 36% of the dwellings visited, mold or mildew on walls or floors in 29%, flies in the kitchen in 37.5%, flies in the toilet in 35.4%, a toilet with adequate ventilation in 85.6% (but screens on the window in only 19%), a clean floor in the bathroom in 60.3%, a washbasin in toilet area in 46.9% and soap readily available for washing hands near the toilet area in 77.5%. Quality inferred from these attributes generally correlates well with imputed rental value. Rental value also depends on the presence/absence of a toilet, suggesting that when rental value is included in the right-hand side it absorbs the impact on the dependent variable of the presence of a toilet. We found that the presence of rats or mice in the dwelling was weakly correlated with illness, but chose to allow other variables that measure the conditions of the dwelling to pick up its effects.

Table 5. Coefficients of Correlation between selected variables (p-value at the bottom of each cell).

	[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]
Mother's education [A]	1										
Water Supply Interruptions [B]	-0.051 0.145	1									
Washbasin [C]	0.183 0.000	0.123 0.000	1								
PAM [D]	0.107 0.002	0.027 0.382	-0.087 0.011	1							
Private Well [E]	0.078 0.022	0.207 0.000	0.352 0.000	*	1						
Hydrant [F]	-0.149 0.000	0.074 0.018	-0.154 0.000	*	*	1					
Vendor [G]	-0.124 0.000	-0.280 0.000	-0.269 0.000	*	*	*	1				
Diarrhea in Household [H]	-0.039 0.269	0.083 0.008	-0.068 0.05	-0.035 0.255	0.017 0.591	0.056 0.072	-0.159 0.608	1			
Wash Hands After Toilet [I]	0.087 0.012	-0.095 0.002	0.064 0.066	-0.071 0.022	0.015 0.622	0.096 0.002	-0.010 0.755	-0.096 0.002	1		
Household Income [J]	0.277 0.000	-0.079 0.011	0.093 0.007	0.128 0.000	-0.091 0.003	-0.057 0.067	0.016 0.602	-0.019 0.541	0.019 0.547	1	
Frequenting Public Toilets [K]	-0.219 0.000	-0.041 0.186	0.127 0.000	0.027 0.382	0.207 0.000	0.075 0.017	-0.280 0.000	0.091 0.003	-0.096 0.002	-0.079 0.010	1
problems with waste in the neighborhood [L]	-0.101 0.004	0.103 0.000	-0.039 0.203	-0.101 0.000	0.131 0.000	0.110 0.000	0.037 0.241	0.113 0.003	-0.057 0.066	0.088 0.004	0.050 0.105

Notes: (i) the figure "0.000" at the bottom of a cell means that the correlation coefficient was significant at the 0.0001 level or better. (ii) an asterisk is entered for water supply modes that are mutually exclusive.

Results from the Simultaneous Equations Model

We are now in position to estimate our simultaneous-equation, bivariate probit model (see Section 2). Table 6 reports estimated coefficients for several specifications of the bivariate probit model. We start from a comprehensive specification that includes all economic variables, variables reflecting public utility and household decisions on the supply of water, and variables reflecting externalities in the production and management of waste. We then gradually drop terms to isolate the impact of household income and the engineering factors. The results of many of our specifications should be interpreted with caution: many regressors are correlated with one another, the usable sample size is often reduced due to the many observations missing for washbasin and mother's education, and these observations are not missing at random, but, rather, primarily among low-income households.

Regression 1 refers to the most comprehensive specification.[19] None of the economic/engineering variables is a significant predictor of diarrheal disease at the 5% confidence level, although the dummy variable for water supply interruptions has a positive coefficient that is significant at the 10% level.[20]

We identify six factors that affect the likelihood of washing hands at the 5% level or better: income, rental value, mother's education, interruptions in the water supply, problems with waste in the neighborhood, and connection to the piped water supply. The likelihood of washing hands rises with income, education, and problems with waste in the neighborhood, and decreases with rental value, interruptions in the water supply and PAM connection. The significance of the coefficient of the interruptions dummy suggests that defensive behavior is severely interfered with by interruptions in the water supply. The negative and significant coefficient of the PAM dummy suggests that persons who obtain most of their water from this source (a highly disrupted one, as shown in tables 2 and 3) might be particularly vulnerable to interruptions.[21] We attribute the negative sign of the coefficient of rental value to the collinearity with other variables and to the sample selection. All coefficients jointly considered are significant at the 5% level: the likelihood ratio (LR) test against the null hypothesis that all slope coefficients are equal to zero takes a value of 62.14 (the 5% critical level for the chi square with 20

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[19] This specification, like all others reported in this paper, essentially models short-term behaviors and illness, and takes all "capital" decisions, such as infrastructure in and around the home and locational choice as given.

[20] A positive coefficient should be interpreted in the sense that, *ceteris paribus*, an increase in the value of the independent variable results in an increase in the likelihood of contracting diarrheal illness.

[21] We also estimated a variant of specification 1 with water source dummies and interaction terms between water source and interruptions. The results indicated that it was best to "consolidate" the interruptions terms into a single interruptions dummy, as is done in specification 1.

degrees of freedom is 31.4). The coefficient of correlation between the error terms of the two equations is negative and significant, suggesting that households with higher than average propensity to wash hands experience lower than average incidence of diarrhea. This result is maintained in all model formulations.

In *specification 2* education and rental value are dropped from both equations to gain degrees of freedom and reduce the biases due to the systematically missing observations. We allow household income, which is highly correlated with education and rental value, to capture their effect.

Relatively large changes are observed in the values and significance of several coefficients in both equations. Four variables turn out to be significant predictors of defensive behavior: supply interruptions, problems with waste in the neighborhood, PAM and vendor dummies. The signs of their coefficients are the same as in specification 1 and their significance is much enhanced relative to specification 1. The coefficient of (log) household income drops in magnitude and significance (it is now not even significant at the 10% level, suggesting that the tendency to wash hands increases only weakly with income), but the coefficients for the washbasin and public toilet dummies become more significant, although only the former reaches the 10% significance level.

In the illness equation two variables are now significant at the 5% level or better: the washbasin and the interruptions dummies. The coefficients of these variables have opposite signs to their counterparts in the washing hands equation, as is consistent with equation (9) of section 2 and with the notion that the defensive behavior matters in preventing diarrheal illness. None of the water source dummies are significant predictors of diarrhea. Nor is frequenting public toilets (a possible source of infection) or the neighborhood waste dummy significant. Log income is negative, but not significant.[22]

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[22] All parameters of the system of equations are jointly significant at the 5% level: the LR test takes a value of 50.60 (the 5% critical value for a chi square with 16 degrees of freedom is 26.30).

Specification 3 drops all water source dummies in an attempt to capture the impact of income on defensive behavior and illness (the household's source of water tends to change systematically with wealth, as is shown in table 1). However, no major changes are observed in the illness equation: the significance of income is not strengthened by omitting variables representing water sources. In the washing hands equation the coefficient of income drops to about one-half of its value and t-statistic from specification 2. All other coefficients remain relatively stable.[23]

In order to explain why income does not matter in either equation, we point out that the likelihood of being connected to the piped water system increases with income: other sources (hydrant, public well, and others) virtually vanish as the household gets wealthier, and the likelihood of taking drinking water from a private well first increases and then slightly decreases with wealth, peaking at middle levels of income. These trends essentially imply that as a household gets wealthier, it typically switches to more frequently disrupted sources of water (Tables 1 and 2).[24] This consideration -- together with the fact that the interruptions dummy is strongly significant in all of our model formulations -- leads us to hypothesize that households *would* tend to wash their hands after the toilet more as they get wealthier *if* this effort were not interfered with by the lack of water due to interruptions.

Specification 4, 5 and 6 offer three possible ways of disentangling the effect of wealth from the effect of water supply interruptions and interpreting their respective impacts on the household with the aid of a term for the interaction of income with water interruptions.

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[23] Finally, the value of the LR test for significance of all parameter is 35.56 and is well above the 5% critical level for the chi square with 10 degrees of freedom (18.31).

[24] The net effect is that wealthier household are *more* likely to experience water supply interruptions: a probit regression of the interruptions indicator on a constant and log income yields a *positive* and strongly significant coefficient on log income.

In *specification 4* we drop the interruption dummy but include its interaction with income. This specification -- a first test for whether the income effect or the interruption effect dominates in predicting hand washing behavior -- essentially allows the likelihood of washing hands and the incidence of diarrheal illness to grow with income at a different rate, depending on whether the household experiences disruptions in water supply.

In the washing hands equation the coefficient of income increases slightly relative to its value in specification 3, but is not significant, implying that even within households without water supply interruptions the tendency to wash hands increases only weakly with the household's economic circumstances. The coefficient of the interaction term is negative, very small in absolute magnitude and significant at less than the 1% level. For households that experience water supply interruptions, the net effect of a rising income on washing hands depends on the *sum* of the coefficients of log income and interruption term (0.0600-0.0250=0.0350).[25] Households with interrupted water supply, therefore, tend to increase their defensive behavior at a "slower" rate when income increases than households with uninterrupted supply. A household will, therefore, not be able to maintain its defensive behavior at the level implied by its higher income if in becoming wealthier it experiences water supply interruptions (as is likely to happen if in becoming wealthier the household switches to piped water or private well).

In the diarrhea equation the coefficient of income is negative and the coefficient of the interaction term is positive and now almost significant at the 5%: these signs are consistent with our priors, suggesting that interruptions obstruct defensive behavior *and* increase the risk of diarrhea.[26]

[25] The marginal effect on the probability of washing hands is obtained as $\phi(bx).(b_{income}+b_{interaction})$, where ϕ is the standard normal density and b is the vector of parameter estimates for the washing hands equation.

[26] The LR test once again confirms significance of all coefficients at the 5% level (the value of the test statistic is 33.82, which is above the 5% critical level for a chi square with 10 degrees of freedom).

In *specification 5* we exclude income and add back the interruption dummy in both equations. This specification allows to check if household defensive behavior responds differently to interruptions, depending on the level of income.

The water supply interruptions indicator is still a significant predictor of washing hands and has a negative coefficient, implying that interruptions do interfere with washing hands. The coefficient of the interaction variable is positive and highly significant in the washing hands equation. This implies that, among households experiencing interruptions, wealthy households are more likely to engage in defensive behavior than poor households.[27] In this model neither the interruptions nor the interaction term are significant predictors of diarrheal illness, the washbasin dummy being the only variable to retain full statistical significance.[28]

Specifications 6 and 7 offer perhaps the purest tests of the economic and engineering models, stripping away all other explanatory variables, and thereby letting the retained variables explain as much of the variation in diarrhea incidence as possible. *Regression 6* essentially repeats -- without any other regressors -- the income/interruptions breakdown of specification 4. At the extended sample size of 1037, income *per se* is significant at the 10% level in the washing hands equation and approaches the 10% significance level in the diarrhea equation. The interaction term is significant at the 1% level in both equations. Because the coefficients of the interaction term are very small, the total effect of a change in income for those households which experience interruptions (*i.e.*, the sum of the coefficients of income and interaction terms) remains positive in the washing hands equation and negative in the illness equation. The

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[27] In order words, consider two households of different economic means both connected to PAM (or using private well water) and facing water supply interruptions. The richer household experiences a less severe disruption in its ability to keep up the defensive behavior.

[28] Jointly considered all parameters are significant (the value of the LR test is 45.42 which is much greater that the 5% critical level for the chi square with 10 degrees of freedom).

low coefficients of log income and of the "net effect" for those households which experience interruptions, however, entail that defensive behavior and illness are not very responsive to economic circumstances.

Specification 7 includes only the interruption variable, an engineering variable that strongly affects the defensive behavior and results in higher likelihood of contracting diarrhea.

Table 6. Bivariate Probit Model Of Washing Hands And Diarrheal Disease. (T-statistics In Parentheses.)

	Specif. 1	Specif. 2	Specif. 3	Specif. 4	Specif.5	Specif.6	Specif. 7
dep. Var.: WASHTOIL							
constant	0.5570 (0.589)	-0.6988 (-0.946)	-0.5569 (-0.780)	-0.6978 (-0.969)	0.0688 (0.903)	-0.9186 (-1.4828)	0.1897 (3.839)
log household income	0.2162 (3.054)	0.0868 (1.547)	0.0494 (0.892)	0.0600 (1.073)		0.0499 (1.7778)	
log imputed rental value	-0.2381 (-3.785)						
education of principal homemaker	0.0202 (2.318)						
washbasin near toilet	0.1205 (1.118)	0.1696 (1.758)	0.2151 (2.387)	0.2108 (2.342)	0.2230 (2.463)		
interruptions in water supply	-0.3151 (-2.909)	-0.3594 (-3.701)	-0.3399 (-3.656)		-4.0806 (-3.488)		-0.2470 (-3.083)
frequent public toilets	-0.9080 (1.362)	-0.6795 (-1.524)	-0.6943 (-1.542)	-0.6821 (-1.518)	-0.6738 (-1.489)		
problems with waste in the neighborhood	0.2457 (2.356)	0.3038 (3.279)	0.3045 (3.339)	0.3006 (3.297)	0.3158 (3.452)		
log household income * interruption in water supply				-0.0250 (-3.423)	0.2954 (3.200)	-0.0064 (-2.6589)	
PAM	-0.4246 (-2.024)	-0.5786 (-3.110)					
private well	-0.0624 (-0.320)	-0.2174 (-1.255)					
vendor	-0.2783 (-1.301)	-0.3827 (-2.035)					
dep. Var.: DIARRHEA							
constant	-0.6439 (-0.528)	-0.3862 (-0.408)	-0.2824 (-0.325)	-0.1480 (-0.193)	-1.1655 (-12.842)	0.0112 (0.0142)	-1.2362 (-18.711)
log household income	-0.0208 (-0.234)	-0.0587 (-0.811)	-0.0692 (-1.021)	-0.0796 (-1.304)		-0.0981 (-1.5689)	
log imputed rental value	-0.0329 (-0.411)						
education of principal homemaker	-0.0018 (-0.164)						
washbasin near toilet	-0.2072 (-1.499)	-0.2552 (-2.046)	-0.2433 (-2.085)	-0.2406 (-2.058)	-0.2499 (-2.147)		
interruptions in water supply	0.2378 (1.733)	0.2468 (2.013)	0.2323 (1.971)		1.8706 (1.353)		0.2670 (2.668)
log household income * interruption in water supply				0.0178 (1.915)	-0.1290 (-1.176)	0.0194 (2.4288)	
frequent public toilets	0.7969 (1.373)	0.2960 (0.622)	0.2869 (0.600)	0.3011 (0.627)	0.2916 (0.613)		
problems with waste in the neighborhood	-0.0175 (-0.133)	0.0064 (0.054)	0.0133 (0.160)	0.0134 (0.123)	0.0131 (0.177)		
PAM	-0.0205 (-0.711)	-0.1368 (-0.595)					
private well	0.2977 (1.144)	-0.0048 (-0.023)					
vendor	0.2822 (0.999)	0.0074 (0.032)					
hydrant							
Correlation coefficient	-0.1816 (-5.383)	-0.1915 (-4.379)	-0.1820 (-2.586)	-0.1832 (-2.603)	-0.1774 (-2.507)	-0.1739 (-2.908)	-0.1779 (-2.098)
sample size	676	834	834	834	834	1037	1037
Log likelihood	-682.41	-851.43	-858.95	-859.82	-854.02	-1103.06	-1104.51

5. Conclusions

We have developed a model of household defensive behavior and illness and empirically estimated it using household-level data collected in Jakarta in 1991. Using a relatively aggregate indicator of illness in the household (the low rates of illness in our data do not allow us to successfully model diarrheal illness separately for adults and children) and a cross-sectional approach,[29] we find that several engineering, economic/behavioral and neighborhood-level variables are associated with illness. The model performs reasonably well, and illustrates that joint modelling of behavior and disease is important: defensive behavior responds positively to opportunity and to the threat of contamination, and disease is in turn controlled by defensive behavior.

Among the engineering variables, poor reliability of the water supply is most strongly associated with diarrheal illness. Interruptions in the supply are consistently found to interfere with defensive behavior (washing hands after using the toilet), *and* to result in higher incidence of diarrhea. Surprisingly, the water sources that supply wealthier households (government-piped water and private wells) have the highest interruptions rates, making those households particularly vulnerable to diarrhea. Given the source of water, a wealthier/more educated household appears to engage in more defensive activities than a poorer household, but the effect of income on diarrhea is weak, to some extent because of the higher frequency of interruptions in the water supply. The availability of a washbasin near the toilet area (another "engineering" variable, which we treat as given in the short term) appears to significantly increase defensive behavior *and* reduce the risk of diarrheal illness.

These conclusions should be viewed more as exploratory than definitive for several reasons. First, with relatively low rates of diarrhea reported among the survey participants, and a highly heterogeneous sample on other grounds, the signal-to-noise

[29] VanDerslice and Briscoe (1993) use data with a longitudinal component collected in Cebu, Philippines.

ratio was relatively low, making hypothesis testing difficult. Second, there were particular difficulties in statistical testing for the effects of water *quality* on diarrhea, because water samples were collected only for 201 out of the 1,037 surveyed households. (For these, one sample from a drinking water container and one from the water source were collected.)

Nevertheless, our results highlight the importance of looking at both economic/behavioral factors and engineering approaches to reducing diarrheal disease, particularly maintenance of a reliable water supply and assuring that housing affords people options for taking defensive measures. Wealthier, better educated households are, in general, better able to undertake defensive behavior. However, we find that for the specific case of Jakarta, economic development strategies that raise personal incomes and education do not necessarily guarantee lower rates of diarrhea. This paradox is at least in part resolved by noting that the most convenient supplies of water sought as incomes rise (household connections) are not necessarily uncontaminated or exempt from interruptions.

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