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Research paper

Endogeneity in water use behaviour across case studies of household water treatment adoption in developing countries

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ABSTRACT

Endogeneity or reverse causality in regression analysis results in biased estimation of the effects of independent variables on the dependent variable and leads to inaccurate interpretations. However, the biased estimation of the effects of psychological factors on water–related behaviours are rarely discussed. This study investigated the endogeneity of psychological factors in water-related behaviour using an instrument variable (IV) approach. Data from eight household water treatment (HWT) studies in Asia, Africa, and South America were utilized. A combination of several socio-economic characteristics, such as education and accessibility, was used as a control variable and three psychological factors, i.e., perception of risk, attitude towards HWT, and social norms, were used as the predictors of the adoption of HWT. Variables related to institutional quality of the countries, based on the World Governance Indicators of the World Bank were used as IVs to predict the psychological factors. The results suggest that endogeneity exists in water-related behavioural studies. Institutions were found to be valid IV for psychological factors attitude and norms, but not for the perception of risk. This suggests that the institutional quality influences households' attitude and norms regarding behaviour. If the feedback effect of actual behaviour on the psychological factors were not considered, the effects of attitude and norms on HWT adoption were underestimated by 59% and 40%, respectively. Finally, despite the challenge of finding valid IV, the endogeneity effect of psychological factors needs to be controlled when estimating the effect of psychological factors on water-related behaviour in future water-related behavioural studies.

1. Introduction

Accelerating the provision of water, sanitation, and hygiene (WASH) services are critical to achieving 100 % safely managed WASH services by 2030. In 2017, there were still about 2.2 and 4.2 billion people without safely managed drinking water and sanitation services worldwide, respectively (UNICEF, & WHO, 2019). One of the challenges of achieving this goal is the water-related behaviour of a target group (Ginja, Gallagher, & Keenan, 2019). Therefore, behavioural change interventions, sometimes called "soft interventions", become essential elements beside infrastructure or technology interventions, or "hard interventions", in WASH projects in developing countries (Peal, Evans, & van der Voorden, 2010).

Human behaviour, including WASH-related behaviour, is directly influenced by an individual's psychology and perceptions (Aunger & Curtis, 2016). "Positive and supportive" psychological factors, e.g. the knowledge of the importance of enacting a behaviour, stimulate individuals to do the behaviour (Mosler, 2012). Hence, understanding the drivers of behaviour is the first step in developing effective behavioural change interventions. Afterwards, a WASH implementer can target critical behavioural drivers to accelerate the behavioural change. It is believed that theory-based interventions will result in more effective behavioural change interventions (Davis, Campbell, Hildon, Hobbs, & Michie, 2015), as there are several success stories of using theory-based interventions in the WASH sector (Lilje & Mosler, 2018; Sonego, Huber, & Mosler, 2013; Tidwell et al., 2019).

Household interviews among the target groups, i.e. quantitative analyses, are often used to analyse factors related to WASH practices (Guiteras, Levinsohn, & Mobarak, 2015; Kesmodel, 2018). The effects of behavioural determinants on WASH practices are often analysed by regressing household psychological variables, as predictors or independent variables, on the behaviour variable, as the output or dependent target variable, by e.g. using ordinary least squares (OLS) or logistic regression (Blanca, Alarcón, & Bono, 2018). These common methods

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often assumes that errors in the dependent variable are uncorrelated with the independent variable (Verbeek, 2017).

However, this assumption might not always hold in behavioural analysis, because there is a possibility of a correlation between the independent variable and the error terms resulting from the "endogeneity" of independent variables (Roberts & Whited, 2012). Endogeneity can emerge as a result of reverse causality or feedback effect from a dependent target variable, e.g. WASH-related behaviour, to the independent variables, i.e. the psychological factors of households (Abdallah, Goergen, & O'Sullivan, 2015; Foster & McLanahan, 1996). For example, when the psychological factor *social norms* is used as a predictor variable to predict the use of water filtration in a community, it is assumed that there is a one-way influence from *social norms* to the behaviour of using water filtration. However, one can suspect that households who already use water filtration in a community influence the *social norms* of that community. This exemplifies a two-way (or bi-directional) feedback between the psychology and the behaviour of households (Fig. 1).

Ignoring the bi-directional feedbacks can lead to biased and inconsistent estimations of the effects and, therefore, inaccurate inferences of psychological factors, e.g., how social norms influence the adoption of water filtration technology (Abdallah et al., 2015). Therefore, the need to analyse it is evident because if the feedback effect is significant, the conventional regression analysis that ignores reverse causality may not be sufficient. A two-stage regression or instrumental variable approach is frequently used to assess this reverse causality (Bascle, 2008).

In order to remedy the potential endogeneity of psychological factors on HWT adoption, an *instrument variable* (IV) is used that "breaks" the reverse causality of the effect of the behaviour on the psychology of households (Fig. 1). The psychological factors do not act as predictor variables *alone*, but as endogenous explanatory variables i.e., predictor variables whose values are determined by other variables or IV. The IVs are then used to first predict the psychological factors and the predicted factors are then used in the second stage regression with HWT adoption to obtain unbiased estimates of the effects of household psychology on the behaviour (Bascle, 2008).

Two-stage regression approach is widely used in econometrics studies to remedy the effects of endogeneity (Roberts & Whited, 2012), but is relatively little used in the field of psychology (Bollmann, Rouzinov, Berchtold, & Rossier, 2019) and water systems and socio-hydrology (Müller & Levy, 2019; Troy, Konar, Srinivasan, & Thompson, 2015). Some studies used IV in WASH-related behavioural studies (Abrahams, Hubbell, & Jordan, 2000; Appiah, Adamowicz, Lloyd-Smith, & Dupont, 2019; Bontemps & Nauges, 2016; Nauges & Wheeler, 2017; Vásquez, Mozumder, & Franceschi, 2015). However, only Vásquez et al. (2015) have used IV in WASH-related behavioural studies in developing countries, based on a study case in urban Nicaragua. In addition, they only used one variable related to the psychological factor, i.e., perception regarding the quality of tap water, and focused more on the context of tap water.

This study focuses on household water treatment (HWT) adoption, i.e. one of the WASH-related behaviours. HWT is a method to treat drinking water at home, such as boiling, water filtration, solar disinfection, or adding chlorine (Sobsey, Stauber, Casanova, Brown, & Elliott, 2008). To the best of our knowledge, there is no study that particularly discuss the endogeneity effect of the HWT adoption in developing countries using more psychological factors, such as perception of risk or norm.

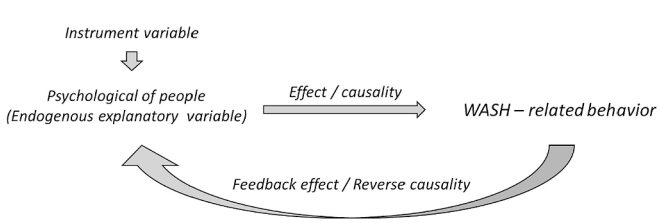

Fig. 1. An illustration of the feedback effect or reverse causality in the WASH-related behaviour analysis.

The first objective of the study was to investigate endogeneity of household psychology in their behaviour of adopting HWT. Three psychological factors were used in the analysis: perception of *risk, attitude,* and social *norms towards the behaviour*. The second objective was to test the validity of institutional quality, or institutions, as the IVs for the endogenous psychological variables. The paper therefore aims to highlight and contribute to the investigation of endogeneity in WASH-related behavioural studies using household surveys from seven countries in Asia, Africa, and South America.

2. Methods

2.1. Datasets

Household survey data from eight HWT studies were utilized in the analysis (Table 1). The data were obtained by contacting the first or corresponding author of the article. The period of data collection varied from 2005 to 2018. In total, there were 4311 respondents interviewed. However, due to incomplete data, 1575 respondents were excluded from the analysis and only the resulting 2736 respondents (63.5 %) were analysed. Examples of the incomplete data were missing information on the HWT adoption, education level, or information related to wealth. Among them, 814 (29.8 %) respondents used HWT, such as solar disinfection, boiling, or water filter. The number of questions asked in the interviews varied. For example, there were 18 questions related to *attitude* in Ethiopia's datasets, but only four questions in Burundi's datasets, and only one in Nepal's dataset. More information about specific datasets can be found in original articles (see the references in Table 1). These 8 datasets are either a cross-sectional study, i.e., no follow up after the survey, e.g., Daniel, Pande, and Rietveld (2020), and Daniel, Sirait, and Pande (2020) or a baseline study in a longitudinal study, i.e., there is a follow-up or intervention after the survey, e.g., (Lilje, Kessely, & Mosler, 2015). For the latter case, the percentage of the use of HWT indicates the number of households using HWT before the intervention or at the baseline study. All these studies were conducted in specific regions of the studied countries. The data of the HWT adoption was reported as either respondent's self-reported HWT practice, e.g., in Nepal's dataset, observation of HWT practices, e.g., in Bolivia's dataset, or combination of self-reported answers and observation, e.g., in Indonesia's dataset.

2.2. Psychological factors: Risk, Attitude, and Norms

Three psychological factors were available across all eight datasets: *Risk, Attitude,* and *Norms* (RAN). They influence the WASH-related behaviour in developing countries (Mosler, 2012). *Risk* represents a person's understanding and awareness of the health risk in relation to drinking water. *Attitude* indicates a person's positive or negative stance towards the HWT adoption. *Norms* denote the perceived social pressure towards the HWT adoption.

There are several sub-factors within each main factor. *Risk* consists of health knowledge, perception of vulnerability, and perception of severity. *Attitude* consists of feelings towards the behaviour and beliefs about benefits and costs. *Norms* comprise descriptive, injunctive, and personal norms. There is usually-one question or information relevant for each sub-factor. All the answers related to psychological factor questions were measured in a five-point Likert scale. Example questions can be found in Mosler and Contzen (2016).

2.3. Control variable: socio-economic characteristics

Socio-economic characteristics (*SEC*) of households were used as control variables (Fig. 1). There are four *SEC* variables which have been

Table 1
Information of the datasets and respondent characteristics.

Country	Indonesia (1)	Indonesia (2)	Nepal	Chad	Ethiopia	Burundi	Zimbabwe	Bolivia
Authors	(Daniel, Pande, et al., 2020; Daniel, Sirait, et al., 2020)	(Daniel, Pande, et al., 2020; Daniel, Sirait, et al., 2020)	(Daniel et al., 2019)	(Lilje et al., 2015)	(Sonego et al., 2013)	(Sonego & Mosler, 2016)	(Mosler et al., 2013)	(Tamas, 2009)
Year of data collection	2018	2018	2014	2014	2010	2012	2007	2005
Total samples after excluding incomplete data (sample size = number of households considered)	282	164	351	473	92	700	480	194
Use HWT	177 (62.8 %)	118 (72.0 %)	72 (20.5 %)	134 (28.3 %)	84 (91.3 %)	63 (9.0 %)	110 (22.9 %)	56 (28.9 %)
Education (in %)								
No Education	10.6	16.5	42.5	42.3	53.5	25.0	8.1	35.1
Primary school	55.7	55.5	24.8	26.4	45.7	1.1	26.3	55.2
Secondary school	12.4	17.7	21.4	26	1.1	43.6	65.2	5.7
Higher education	21.3	10.4	11.4	5.3	0.0	30.3	0.4	4.1
Diarrhea in children (%)	35.1	55.5	2.3	44.0	82.6	49.7	16.0	17.0
Easy accessibility (%)	48.6	52.4	45.6	83.9	26.1	40.3	52.5	38.7

*if the percentage does not reach 100%, it means there is a missing data in that variable.

linked to the HWT adoption and were available across all datasets: wealth (Opryszko et al., 2010; Roma, Bond, & Jeffrey, 2014), education level (Fotue Totouom, Sikod, & Abba, 2012; Freeman, Trinies, Boisson, Mak, & Clasen, 2012; Nauges & Van Den Berg, 2009), accessibility (Dubois et al., 2010), and whether any children or household members get water-related diseases, e.g., diarrhoea or fluorosis (Christen et al., 2011; Freeman et al., 2012). Education level was recorded as years of education or standard education level, i.e. "no education", "primary school", "secondary school", etc., in the datasets. Accessibility in this study is defined as the distance to the main market or the length of a supply chain. The surveys also considered whether there were water-related disease cases in the household. For measuring wealth, all datasets relied on household's assets or income. These four characteristics are often measured in national demographic surveys, such as the Demographic Health Survey (Croft, Marshall, & Allen, 2018).

2.4. Instrument variable (IV): Institutions

The IV should be such that it is *directly* related to the psychological factors, and only *indirectly* to the behaviour, i.e. the influence of IV on the behaviour is "mediated" by the psychological factors. Finding an IV that meet those criteria is challenging (Foster & McLanahan, 1996). One of the potential IV for *risk*, *attitude*, and *norms* (RAN) is institutional quality or institutions. An institution is defined as "a system of social factors that conjointly generates a regularity of behaviour" (Greif, 2006). Alesina and Giuliano (2015) argue that institutions are endogenous variables, which may be influenced by history, political system, or geographical situation, reflecting emergent local culture and could influence the psychology of people that are responsible for household's behaviour in general.

In the IBM-WASH model, five aggregate levels of WASH behaviour has been identified (from top to bottom): societal/structural, community, interpersonal/household, individual, and habitual (Dreibelbis et al., 2013). The top level *societal/structural level* points to institutional, organisational, policy, and cultural factors that influence the WASH behaviour. The psychological factors, RAN, are located in lower levels: interpersonal/household, individual, and habitual. It is assumed that institutional quality is a potential instrumental variable for RAN, in which strong institutions facilitate appropriate WASH behaviour (Barstow, Nagel, Clasen, & Thomas, 2016; Curtis, 2019; Jiménez, Mtango, & Cairncross, 2014). Strong institutions or good governance are characterised by, for example, the existence of a legal framework, clear short and long term strategies, and full compliance (Hamer, Dieperink, Tri, Otter, & Hoekstra, 2020).

Moreover, other studies and psychological frameworks indicate that contextual factors, e.g., institutions, wealth, education, etc., influence indirectly the WASH-related behaviour (Daniel, Pande, et al., 2020; Daniel, Sirait, et al., 2020; Figueroa & Kincaid, 2010; Rainey & Harding, 2005). This also supports that institutions are valid IVs to treat the endogeneity of psychological factors.

"Many sociologists treat all institutions as social norms" (Dequech (2006), often because the latter are influenced by the former (Legros & Cislaghi, 2020). The institutions may also be correlated with the perception of *risk* and *attitude*. For example, trust in governmental agencies of water supply could influence the perception of the quality of distributed water (Doria, 2010). There could also be an interplay between institutions, the perception of risk, and attitude that influences a household's decision to treat water, for example regarding smell, taste, colour, and turbidity aspects of distributed water (Crampton & Ragusa, 2016; Jain, Lim, Arce-Nazario, & Uriarte, 2014). Thus, while there is strong literature evidence to support that the quality of institutions is correlated with RAN, especially with social norms, it remains to be tested whether the quality of institutions is a "valid" IV.

One of the ways to measure the "quality" of institutions is in terms of governance indicators. Governance is defined as "the traditions and institutions by which authority in a country is exercised" (Kaufmann, Kraay, & Mastruzzi, 2010). Kaufmann et al. (2010) define six dimensions of governance: (1) Voice and Accountability, (2) Political Stability and Absence of Violence/Terrorism, (3) Government Effectiveness, (4) Regulatory Quality, (5) Rule of Law, and (6) Control of Corruption. Together with the World Bank, Kauffman et al. (2010) developed the governance indicator scores that estimates the governance performance of all countries worldwide every year since 1996. The scores, called the Worldwide Governance Indicators (WGI), represent general perceptions of the respondents on countries' performance with regards to the six dimensions and vary from −2 to +2. The scores are constructed in a way that allows meaningful comparison across countries. Low scores mean that a country is weak with regard to the specific indicator and countries with higher scores are performing better. Detailed information and definition can be found in Kaufmann et al. (2010).

2.5. Two-stage regression

If *HWT adoption* is coded as a binary variable, i.e., "yes" or "no", it is in the paper assumed that probability of (*HWT adoption* = yes) for households *i* follows a logistic distribution. The *SEC* of households act as a control variable, i.e., *SEC* is treated as a single variable to simplify the Eq. (1). The parameters b_2 *to* b_4 quantify the corresponding effects of the independent variables on HWT adoption and ε is the error term. Here *i*

represents a household:

$$P(HWT\ adoption_i = yes) = \frac{1}{1 + e^{-(b_0 + b_1 SEC_i + b_2 Risk_i + b_3 Attitude_i + b_4 Norms_i)}} \quad (1)$$

If there is reverse causality from *HWT adoption* to all psychological factors, the error in Eq. (1) will be correlated with psychological factors, leading to biased and inconsistent estimation of parameters b_2 *to* b_4. In this situation, the variables *risk*, *attitude*, and *norms* are called endogenous explanatory variables.

In order to remove this effect of reverse causality, appropriate IVs are identified and two-stage regression is performed. A valid instrument variable is one that only indirectly influences the dependent variable via the endogenous variables. The correlation between errors and the endogenous variables is thus reduced by regressing the endogenous variables on the IV in the first stage and then using the "predicted" endogenous variables as independent variables in the second stage with the dependent variable. For example, if *norms* is an endogenous explanatory variable and at least one instrument variable is used to predict *norms* using a standard regression analysis (Eq. (2)). This is the first-stage regression, where γ is i.i.d. variable and a_0 and a_1 are first stage regression parameters.

$$Norms_i = a_0 + a_1 IV_i + \gamma_i \quad (2)$$

In the second-stage regression, the predicted *norms* ($\widehat{norms}$) is then used. This is obtained based on regression in Eq. (3) and used to explain the variance of the dependent variables, instead of using the *norms* obtained directly from the respondent interview. Hence, the Eq. (1) is then updated to a new logistic regression equation, i.e. the second-stage regression (Eq. (3)).

$$P(HWT\ behaviour_i = yes) = \frac{1}{1 + e^{-(b_0 + b_1 SEC_i + b_2 Risk_i + b_3 Attitude_i + b_4 \widehat{Norms_i})}} \quad (3)$$

It is important to note that weak instrument variable will provide a poor prediction of the endogenous explanatory variable in the first-stage regression. Consequently, the model performance in the second-stage is also determined by the performance of the first-stage regression. Thus, it is crucial to select a highly correlated IV for the analysis.

2.6. Data analysis

Since there was more than one question related to each RAN psychological factor (2016), Principal Component Analysis (PCA) was performed to capture the dominant axes of variations linked to *risk*, *attitude*, and *norms* respectively. For example, there were three questions related to *norms*: personal, descriptive, and injunctive norms. Assuming that responses to these questions might be correlated, PCA was used to obtain their principal component, called *norms*. This then represents the dominant axis along which norms related psychology of households varies. The same approach was used to reduce the dimensionality of *risk* and *attitude* related factors; see the same approach used by Daniel et al. (2019), Daniel, Pande, et al. (2020) and Daniel, Sirait, et al. (2020). The exception was for datasets where only one question related to a psychological factor was available. For example, there was only one question related to *attitude* in dataset for Nepal study.

Before analysing the *SEC* of the respondents, the respondents' years of education was converted into "no education", "primary school", "secondary school", and "high school and higher" in some datasets which measured the education level by years of education to allow dataset inter-comparison. For accessibility, the urban area was coded as "easy access" (1) and the rural area as "difficult access" (0). Furthermore, households with water-related diseases were coded 1 and 0 otherwise. For datasets that collected household's assets (five datasets), we used PCA to create the relative wealth index (Houweling, Kunst, & Mackenbach, 2003); but for datasets which collected household's income (three datasets: Ethiopia, Zimbabwe, Bolivia), it was used directly to measure the relative wealth index.

To capture the general *SEC* of the respondents, we combined four SECs using PCA: wealth, education, accessibility, and presence of water-related disease. The first principal component scores, called *SEC*, were used in the analysis.

For the IV, the values of six governance indicators of those countries in the year of data collection were used. For example, for the case of Zimbabwe where the households survey was conducted in 2007, the WGI scores of Zimbabwe for 2007 was used. In case of Indonesia, an exception was made. The scores of 2017 were used even though the households survey was conducted in 2018. That was because 2017 was the last year for which WGI scores were available.

An OLS regression in the first-stage regression, i.e., three regressions with *institutions* as the independent variables for *risk*, *attitud*e and *norms* respectively, was conducted. The HWT adoption was coded as a binary variable in all eight datasets, either "yes" (practice HWT) and "no" (do not practice HWT)". Therefore, logistic regression was used in the second-stage regression, i.e., *HWT adoption* as the output variable (Friedrich, Binkert, & Mosler, 2017; Kraemer & Mosler, 2010). All eight datasets were pooled into one and unweighted logistic regression was performed in the second stage. The main assumption that we used in the pooled data is that the education, wealth, and accessibility in all eight study locations have similar effects on the HWT adoption. For example, the influence of level of education, e.g., primary education level, in all study locations on the HWT adoption is the same.

A valid IV should meet two conditions: (1) relevance: it should be (strongly) correlated with the endogenous explanatory variable, i.e., RAN, and (2) exogeneity: it should not be correlated with the output, i.e., HWT adoption, after controlling for the endogenous explanatory variable and other regressors or control variables in the output equation (Becker, 2016; Tabellini, 2010).

The first assumption was tested empirically by OLS regression of IV, i.e. WGI scores, on each psychological factor, i.e. *risk*, *attitude* and *norms*. We assessed the relevance of IV by looking at: (1) the R^2 value (strength of correlation), and (2) an *F*-test of all the regressions (Bound, Jaeger, & Baker, 1995). As a rule of thumb, the *F*-stats above 10 suggesting that the assumption of weak IV are not violated (French & Popovici, 2011). Furthermore, even though there is no formal agreement on the R^2 value, R^2 value above 0.25 as a threshold for good correlation was used. Only IV that pass both conditions were considered.

In contrast with the first assumption that can be tested empirically and easily, it is more challenging to fulfil the exogeneity assumption, i.e., find IV which is not correlated or significant at all with the output variable in the presence of the endogenous explanatory variable in the regression equation. We argue that culture is the main conduit of the influence of institutions (IVs) on HWT adoption behaviour and that any remaining correlation between IVs (in presence of endogenous variables) and the HWT adoption is due to "culture" variable used in the analysis not being exhaustive. There may still be missing endogenous variables through which institutions are influencing the outcome variable and hence the correlation (and the challenge to fulfill the exogeneity condition). Note however, this still breaks the endogeneity of the selected culture variables (RAN: Risk, Attitute, Norms in our study) when estimating its effect on HWT adoption. We also notice that some WASH-related studies have not tested this second assumption (Appiah et al., 2019; Bennett, 2012; Díaz & Andrade, 2015; Pande, Keyzer, Arouna, & Sonneveld, 2008; Vásquez et al., 2015). However, the approach of Tabellini (2010) was followed to test the exogeneity assumption in this study. This was done by regressing the *SEC*, predicted psychological variables (psychological factors as predicted by IV of choice in the first stage), the remaining psychological factor (the psychological factor that is not treated as endogenous), and the used IV on *HWT adoption*. The validity of the IV was verified if the regression coefficients corresponding to the IV turned out to be insignificant.

Moreover, to avoid multi-collinearity, different combinations of governance indicators for each of the psychological factors were

considered in the first-stage regression. For example, if the indicator *political stability* was used as IV for *attitude,* it was not used as the IV for *norms*. Various possible combinations of WGI indicators were then sought and potential combinations were selected using three criteria: (1) the R^2 between IVs and psychological factor must be above 0.25, i.e., to indicate good prediction, (2) the predicted endogenous psychological factors must be significant in the second stage regression, i.e. in the logistic regression to predict *HWT adoption*, and (3) meet the second assumption of a valid instrument. Wald tests were also conducted for exogeneity to test whether the instrumental variable approach was suitably compared to the standard regression analysis, i.e., whether the "suspected" psychological variables were indeed endogenous.

Afterwards, the second-stage logistic regression was performed (Eq. (3)) and compared the results with the "non-instrumentalised" logistic regression (Eq. (1)), i.e. logistic regression of *HWT adoption* without removing the endogeneity effect of psychological factors.

3. Results

The Wald tests show that *attitude* and *norms* were endogenous, giving χ^2 values of 49.04 and 126.80, respectively (both significant < 0.001). The validity of the IVs was then first tested before performing the two-stage regression. The results of the first assumption, i.e. IVs are strongly correlated with the endogenous variable, are shown in Table 2 and 3. When all six indicators were used to predict RAN in multiple linear regressions (all six indicators inserted at once as predictors), the R^2 was relatively low for *risk,* but quite high for *attitude*, and *norms* (Table 2). Furthermore, one-to-one linear regressions between each WGI indicators and RAN were investigated. The results show that a single WGI indicator was weakly correlated with *risk* and *attitude*, but reasonably correlated with *norms*, giving an average R^2 of 0.179 (Table 3). The results of Table 2 and 3 indicate that: (1) WGI indicators were weak IV for *risk* and (2) multiple WGI indicators needed to be used to predict *attitude* and *norms* in order to increase the R^2 value between respective observed and predicted psychological variables. Therefore, *risk* was treated as an exogenous variable in the next analyses. Moreover, all six indicators were found to be significant predictors of *norms* in multiple linear regressions (Table 2) where the average R^2 for *norms* was the highest (Table 3), indicating that governance indicators were more related to the social norm, compared to *risk* and *attitude*.

The one-to-one regression between each WGI indicator and each RAN gave for 13 out of 16 significant relationships, positive correlations

Table 2
Unweighted multiple linear regression of *all* six governance indicators on Risk, Attitude, and Norm[a].

Independent variables	Dependent variables		
Governance indicators	Risk	Attitude	Norms
Voice and accountability	1.333 (0.672)*	−0.033 (−0.015)	1.831 (0.175) *
Political stability and absence of violence or terrorism	−1.936 (−0.748) *	−3.211 (−1.130) *	−5.128 (0.301) *
Government effectiveness	−0.358 (−0.160)	−3.304 (−1.349) *	−1.966 (−0.862) *
Regulatory quality	3.190 (1.672) *	4.219 (2.015) *	2.076 (1.064) *
Rule of law	−6.837 (−2.647) *	−11.025 (−3.888) *	−7.372 (−10.425) *
Control of corruption	3.269 (1.265) *	12.016 (4.237) *	9.944 (3.765) *
R^2	0.163	0.441	0.344

*significant at 0.001 level; **significant at 0.05 level; the value inside the parentheses is the standardised coefficient (β); [a] all six indicators were inserted at once in the analysis; All F statistics > 10.

Table 3
Unweighted linear regression of *each* six governance indicator on Risk, Attitude, and Norm.[b].

Independent variables Governance indicators	Dependent variables					
	Risk		Attitude		Norms	
	B	R^2	B	R^2	B	R^2
Voice and accountability	0.346*	0.030	−0.298*	0.019	0.814*	0.161
Political stability and absence of violence or terrorism	−0.029	0.001	0.941*	0.110	0.798*	0.091
Government effectiveness	0.291*	0.017	0.397*	0.026	1.119*	0.241
Regulatory quality	0.333*	0.030	−0.551*	0.069	0.771*	0.156
Rule of law	0.256*	0.010	−0.451*	0.025	1.168*	0.196
Control of corruption	0.059	0.001	0.631*	0.050	1.264*	0.229
Average R^2		0.015		0.050		0.179

*significant at 0.01 level; [b] the indicator was inserted one-by-one in the analysis; All significant coefficients have F statistics > 10.

(Table 3), indicating that good institutions' performance, i.e. higher scores of WGI indicators, positively stimulated the psychology of HWT adoption.

To avoid multi-collinearity, combinations of WGI indicators were investigated that could predict *attitude* and *norms* using the three criteria that have been mention previously (section data analysis). Two combinations were found that met those three assumptions: (1) *Voice & accountability* and *Government effectiveness* to predict *attitude* (R^2 = 0.252), and (2) *Political stability and absence of violence or terrorism* and *Control of corruption* to predict *norms* ($R^2 = 0.295$). The predicted *attitude* and *norms* were also significant in the second stage regression (Table 4, column 2). Furthermore, the second assumption of a valid instrument was also fulfilled (Table 4 column 3–5). These IVs were not significant at p-value < 0.001, when included in the logistic equation with other predictors, i.e. *SEC*, *risk*, and predicted *attitude* and *norms*.

We further performed the standard logistic regression using *SEC* and RAN as predictors of *HWT adoption* to compare its results with the two-stage regression. The coefficient (B) of the "suspected" endogenous variables *attitude,* and *norm* were 0.758, and 0.790, respectively. The equation explained 30 % of the variance in the output variable *HWT adoption*, and *norms* appeared to be the most important predictor (highest β).

Table 4 column 2 shows the results of the second stage regression. The coefficients of the endogenous variables *attitude* and *norms* were 1.203 and 1.104, respectively, and the R^2 was 0.210, being lower than the standard logistic regression (0.300) (Table 5). The reduction in explained variance can be attributed to the first stage regression of endogenous variables on IVs, which have low variability. However, the effect of *attitude* and *norms* on HWT adoption was underestimated by the standard logistic regression, i.e. B = 0.758 and 0.790, respectively (Table 5) in standard logistic regression, compared to B = 1.203 (59 % higher) and 1.104 (40 % higher), respectively, (Regression(1), Table 4 column 2) in the second-stage regression or when *attitude* and *norms* were treated as endogenous variables and controlled for it. Additionally, *norms* was the most important psychological factor in the standard regression (highest β, Table 5), but *attitude* became the most important psychological factor in the two-stage regression approach (Regression (1), Table 4 column 2), while *risk* remained the least important factor in both approaches.

4. Discussion

This paper found that psychological factors are endogenous in water-

Table 4
Testing the second assumption of instrument validity: Unweighted logistic regression of selected governance indicators as IV, socio-economic characteristics of respondents (*SEC*), exogenous psychosocial factor, and predicted endogenous psychosocial factors on HWT adoption.

Independent variables	Coefficients (B) in HWT adoption				
	Regression 1a	Regression 1b	Regression (2)	Regression (3)	Regression 4
SEC	0.483* [0.584,0.382]	0.565* [0.677,0.452]	0.479* [0.584,0.374]	0.504* [0.609,0.400]	0.495* [0.599,0.390]
Risk	0.197* [0.281,0.114]	0.126** [0.222,0.030]	0.200* [0.285,0.114]	0.198* [0.281,0.115]	0.229* [0.318,0.141]
$\widehat{Attitude}$	1.203* [1.378,1.028]	1.514* [1.720,1.308]	1.191* [1.391,0.990]	1.152* [1.330,0.976]	0.927* [1.203,0.652]
$\widehat{Norm}$	1.104* [1.253,0.956]	1.456* [1.633,1.280]	1.148* [1.519,0.778]	0.991* [1.185,0.798]	1.329* [1.705,0.952]
Voice & accountability			−0.051		−0.587***
Political stability and absence of violence or terrorism				0.258	0.617**
Government effectiveness			n.a.		n.a.
Control of corruption				n.a.	n.a.
Pseudo R^2	0.210	0.360	0.210	0.211	0.213

*significant < 0.001; **significant < 0.01; ***significant < 0.05; the value inside the parentheses is the confidence interval; n.a. variable is omitted from the analysis due to redundancy. $\widehat{attitude}$ is predicted by *Voice & accountability* and *Government effectiveness*; $\widehat{norms}$ is predicted by *Political stability and absence of violence or terrorism* and *Control of corruption*.

Table 5
Unweighted logistic regression of socio-economic characteristics of respondents (*SEC*), *Risk*, *Attitude*, and *Norm* on HWT adoption (dependent variable).

Independent variables	B	SE B	β
SEC	0.489*	0.053	1.631
Risk	0.124**	0.045	1.132
Attitude	0.758*	0.050	2.134
Norms	0.790*	0.047	2.203

*$p \leq 0.001$, ** $p \leq 0.01$, Pseudo $R^2 = 0.300$, n = 2736.

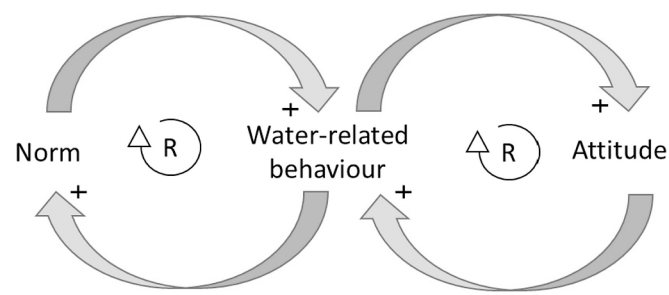

Fig. 2. The psychological factors and the HWT adoption are mutually reinforcing.

related behaviour and the endogeneity of *attitude* and *norm* led to a biased estimation of the corresponding effect by 59 % and 40 %, respectively. All predictors, i.e., *SEC* and psychological factors, positively influenced the HWT adoption, as showed by the positive coefficients, which indicates that households that have favourable, i.e., better conditions of, *SEC* and psychological factors are more likely to treat their drinking water. The analysis shows that the most important psychological factor changes from *norms* in the non-instrumentalized logistic regression to the *attitude* in the two-stage regression. Another observation is that the psychological factor *risk* seems to be less important when compared to attitude and norm in influencing the HWT adoption. A person's awareness of risk is not enough to sustain the water-related behaviour, as also suggested by the previous multi-country review (Lilje & Mosler, 2017). Apparently, the personal feeling or satisfaction after using the water-related technology and external nudges from outside or society are more important to drive the behaviour, as also proposed by the theory of planned behaviour (Ajzen, 1991).

The existence of endogeneity in water-related behaviour suggests the need to analyse the feedback effect from behaviour to psychological factors. This feedback effect will lead to a total effect in the system that is "reinforcing" itself, i.e. the psychological factors and the behaviour are mutually reinforcing (Huber, Viscusi, & Bell, 2017; Latkin et al., 2013) (Fig. 2). It means that the accumulation of positive norms and attitude perceptions in a community could increase the use of HWT, both in terms of regularity, and quantity, i.e. from few number of users to more HWT users. For example, the more people use HWT, the higher the norms in the society to treat drinking water, and this will attract even more people to use HWT. The same situation may apply to the perception of attitude, since people who use HWT are more likely to have a positive attitude towards treated water by HWT and then influence their peers to use HWT. One can also estimate the strength of reverse causality and model the dynamic changes in psychological factors and water-related behaviour, for example, using a system dynamic model that conceptualizes bi-directional feedbacks between the two.

The study confirms that *institutional quality*, as represented by the governance indicators, is one of the potential IVs for psychological factors. The results show that good institutions, showed by higher scores of the WGI indicators, lead to favourable psychological factors in the water sector. For example, a regulation by a municipality can lead a social norm to treat drinking water. Economic incentives by the municipality can also allow low-income people to afford water-related technology, i.e. influencing attitudes related to cost. This supports the argument that institutions can either catalyse or inhibit the adoption of water-related technologies or behaviours (Bromley & Anderson, 2018; Pande et al., 2020; Pande & Sivapalan, 2017).

The governance indicators are closely related to norms, as also suggested by others (Dequech, 2006; Legros & Cislaghi, 2020). One of the interpretations is that institutions are products of culture, and culture is closely linked to the social norms of a society (Alesina & Giuliano, 2015; Tabellini, 2010). Another study has mentioned that values, beliefs, and norms are part of the culture (Roobavannan et al., 2018). We, therefore, argue that institutional quality is an appropriate instrument for norms. Furthermore, the present study also confirmed that the perception of attitude is endogenous to institution's performance (Crampton & Ragusa, 2016; Doria, 2010; Jain et al., 2014; Vásquez et al., 2015).

The perception of risk had a low correlation with the IVs used in this study and, therefore, not treated as endogenous in the analysis, even though previous studies show that the risk perception of people can be endogenous to their water use behaviour (Crampton & Ragusa, 2016;

Doria, 2010; Jain et al., 2014; Vásquez et al., 2015). However, those studies also imply that perception of attitude may mediate the impact of institutions on risk and diminish the "direct effect" of institutions on risk perception. For example, unreliable treatment processes and services by a water supplier, i.e. one of the indicators of weak institutions, may result in bad taste and odour of the tap water, i.e. one of the attitude aspects. People may then perceive that the chance of getting sick due to drinking untreated water is high, i.e., perception of risk. Furthermore, since this study could not solve the endogeneity problem in risk, future studies should find appropriate IV for risk, maybe variables outside institutions.

The use of institutional quality as IV has a major limitation. Institutional quality as an IV is mainly applicable for comparative analyses, where behaviour in different contexts or locations are studied, unless information on the local institutional setting is obtained as well. Therefore, the IV approach is strongly suggested in analysing water-related behaviours if a good IV for psychological factors can be found. Future studies need to consider other choices for instrumental variables. Moreover, using the same institutional values for all households in the same country may not fully capture heterogeneity in institutional quality and associated culture (WASH related behaviour) across households within a single country. For example, the quality of institutions may differ between urban and rural areas. Furthermore, there are variations in psychological questions used in all datasets. For example, only one question related to the attitude appeared in the Nepal dataset. Thus, the attitude data that was used in the analysis may not fully represent the variable. Furthermore, the household data do not fully represent the whole population of the countries, since the data were only taken in specific areas. Finally, the deletion of more than one-third of the total respondents (n = 1675) from analysis due to missing values may have a consequence on the interpretation of the results. The missing values occur mainly in large datasets: 542 respondents in Chad's dataset, 367 in Zimbabwe's dataset, and 342 in Bolivia's dataset, i.e., 75 % of the total missing values. However, since the numbers of respondents in those datasets are already large enough and there are still large respondents remaining (Table 1), we consider that the results still represent the sampled population in the study area. However, we acknowledge that the missing values reduce the statistical power of our results.

5. Conclusion

This study used data of eight HWT studies in low-middle income countries to investigate the endogeneity in HWT adoption. Instrumental variable approach was performed in this study. Variables related to institutions, which are represented by governance indicators, were used as IV to tackle endogeneity in the psychological factors *attitude* and *norms*. Results demonstrated that institutional quality directly influence the attitude and social norms related to water technology or behaviour. In contrast, institutional quality was not a good instrument for *risk*, indicating that perception of *risk* is not directly influenced by institutions. We confirmed that endogeneity exists in the water behavioural system. The second-stage regressions showed that attitude towards water technology or behaviour is the most important psychological factor to make households use HWT, followed by the social pressure from the community, i.e. social norms, while the perception of risk had only half of the effect of *attitude* and *norms*. Moreover, the effect of *attitude* and *norms* were larger when treated for endogeneity. This study thus underlines the need to treat psychological factors as endogenous variables in water or WASH-related behavioural analyses.

CRediT authorship contribution statement

D. Daniel: Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization. **Saket Pande:** Conceptualization, Methodology, Software, Validation, Writing – review & editing, Supervision. **Luuk Rietveld:** Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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