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The Piped Water and Household Food Consumption: Evidence from Cambodia

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ABSTRACT

This study analyses the effects of piped water on household food consumption per capita by adopting inverse-probability-weighted regression adjustment and endogenous treatment effects approaches with data from the Cambodia Socio-Economic Survey carried out in 2013 and 2017. A complementary analysis of the effects on primary household income per working-age member is also conducted to give insights into the potential consequences. The study also conducts a robustness check by estimating the fixed effects of piped water utilising village panel data. The results suggest that households using piped water are likely to enjoy higher food consumption per capita, with a complementary finding demonstrating that the use of piped water is likely to increase household income per working-age member.

KEYWORDS

Piped water; Food consumption; Income; Cambodia

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1. Introduction

The insufficient and unsafe water is likely to put a serious threat to labour productivity through human health in the underdeveloped communities, in the developing world in particular. A large burden of diseases, such as diarrhea, respiratory infections and malnutrition, and many neglected tropical diseases, affected over 1 billion people in 149 tropical and subtropical countries (Asia Development Bank [ADB], 2019; World Health Organisation [WHO], 2019). Ensuring all people's access to sufficient and safe water, and sanitation under better management of water resources helps improve the health and life quality of millions of individuals. However, alongside the economic growth and development in developing countries, chemical impurities resulted from untreated industrial waste and excessive use of agricultural fertilizers and pesticides have become increasingly major contaminants in drinking water (Zhang & Xu, 2016). One of the United Nations' sustainable development goals is to achieve "universal and equitable access to safe and affordable drinking water for all by 2030." The governments in developing countries and international donors have supported water infrastructure projects on improving water supply and household welfare to reach this goal (Frempong, Kitzmüller, & Stadelmann, 2021).

A large number of studies empirically tested the effects of access to safe water and sanitation on health outcomes and water collection times (e.g., Jalan & Ravallion, 2001; Gamper-Rabindran, Khan, & Timmins, 2010; Kremer, Leino, Miguel, & Zwane, 2011; Devoto et al., 2012; Augsburg & Rodríguez-Lesmes, 2018; O'Gorman, 2021; Frempong et al., 2021), some others quantified the impacts on child education outcomes (e.g., Mangyo, 2008, Koolwal & Van de Walle, 2013; Zhang & Xu, 2016; Choudhuri & Desai, 2021). These studies confirmed the beneficial effects on mental and physical health, water collection times and child education. Because health has also a positive correlation with such individuals' labour market outcomes as labour supply, productivity and self-employment profits (Strauss, 1986), and wage rates (Thomas & Strauss, 1997), the access to safe water is likely to improve household livelihoods. Nonetheless, some studies performing randomized controlled trial (RCT) experiments indicate that it has no impacts on health (e.g., Pattanayak et al., 2007; Clasen et al., 2014; Patil et al., 2014; Frempong et al., 2021).

Regarding Cambodia, in 2017, approximately 73 per cent of the rural Cambodians had access to improved water supply, of which 11 per cent was piped (ADB, 2019). Many residents in the rural communities spend much of their times and financial resources accessing to daily drinking water from distant sources, collecting rainwater, or getting it offered to their homes. Poor quality of drinking water and sanitation cause diarrhea, causing many children to suffer illnesses such as stunting, impaired brain development, infant and under-five mortality. Approximately 30 per cent of the under-five children had stunted growth, with the prevalence of 10 per cent being higher among those born to mothers from the 40 per cent lowest income quintile (ADB, 2019). This reveals that the limited access to sufficient and safe water is a health challenge for the rural communities. However, the study of developmental effects of piped water, in particular on household food consumption, is scanty in Cambodia's case.

While there has been growing studies on the effects of access to safe water on child education and health outcomes, knowledge remains limited concerning the consequences for household food consumption. Then, this article aims to analyse the impacts of piped water, defined as tap water connected with the distribution lines of a piped water supply station, on household food consumption per capita in Cambodia by using the Cambodia Socio-Economic Survey conducted in 2013 and 2017. The main pathway to improving livelihoods, ensuring food security and nutrition, and reducing poverty is the sufficient food consumption (e.g., Alem & Söderbom, 2012; Carpena, 2019; Adong, Kornher, Kirui, & Braun, 2021). Because access to safe water is likely to determine the productivity of labour (Strauss, 1986; Thomas & Strauss, 1997), the use of piped water is likely to affect household food consumption. Hence, understanding the potential of improving food consumption through safe drinking water is of food security policy relevance. The article contributes to the literature by providing empirical evidence of the potential consequences of piped water for household food consumption with household productivity being considered as a potential mechanism. In so doing, a complementary analysis focuses on the effects of piped water on household productivity in terms of primary household income per working-age member.

Quantifying the impacts of piped water usage is subject to non-random problem, with the decision to use piped water being made by individual households, resulting in endogenous section bias. Addressing this problem, inverse-probability-weighted regression adjustment (IPWRA) approach is adopted to estimate the unbiased treatment effects. Furthermore, there is potential effects of unobserved confounders on both the household decision and food consumption per capita as well as income per working-age member, which cannot be addressed by the IPWRA procedure, then still causing bias and inconsistent estimates. To account for these challenges, an endogenous treatment effects (ETE) model is also utilised. In addition, the study adopts a village-fixed-effects approach with panel data constructed at the village levels to conduct further robustness analysis. The results from these approaches are consistent, with a conclusion that households using piped water enjoy higher per capita food consumption and primary income per waking-age member. Arguably, the potential mechanism underlying the favourable effects is likely to be through promoting household labour productivity.

The remainder of the study is structured as follows: Section 2 reviews the relevant literature, Section 3 discusses the analytical framework, Section 4 describes the data sources with descriptive statistical analysis, Section 5 presents the estimated results, and the final section concludes the study.

2. Literature Review

Starting with the early studies (e.g., Blum & Feachem, 1983; Esrey, Feachem, & Hughes, 1985; Esrey, Potash, Roberts, & Shiff, 1991), the health effects of safe water were extensively quantified by a strand of literature (e.g., Aiello, Coulborn, Perez, & Larson, 2008; Amrose, Burt, & Ray, 2015; Ejemot-Nwadiaro et al., 2015; Loevinsohn et al., 2015; Norman, Pedley, & Takkouche, 2010; Taylor, Kahawita, Cairncross, & Ensink, 2015; Jalan & Ravallion, 2001; Gamper-Rabindran, Khan, & Timmins, 2010; Kremer, Leino, Miguel, & Zwane, 2011; Devoto et al., 2012; Augsburg & Rodríguez-Lesmes, 2018). The findings suggested certain beneficial effects of safe water on health in both low- and middle-income countries, confirmed by the most recent studies (e.g., Augsburg & Rodríguez-Lesmes, 2018; O'Gorman, 2021; Khan & Sheikh, 2023). Other strand of literature assessed the impacts on child education outcomes, also providing the evidence of the desirable effects (e.g., Mangyo, 2008, Koolwal & Van de Walle, 2013; Zhang & Xu, 2016; Choudhuri & Desai, 2021), while the others found no health effects (e.g., Pattanayak et al., 2007; Clasen et al., 2014; Patil et al., 2014; Frempong et al., 2021).

O'Gorman (2021), applying logistic model to the adult version of the First Nations/Inuit survey in Canada for 2002/3, 2008–10, and 2015–16, found that access to piped and running water has the beneficial effects on both mental and physical health. Moreover, Augsburg and Rodríguez-Lesmes (2018) quantified the impacts of quality of water on child health in India by using an instrumental variable (IV) approach with data at the community level. The findings suggest that the water quality plays a significant and positive role in height growth during the early childhood, especially for girls. Moreover, Frempong et al. (2021) analysed the effects of improved water provision on health outcomes by applying fixed-effect panel data models to individual panel datasets at the sub-county level in Uganda. They found that the improved water sources contribute to improved water usage and reducing water collection times.

Regarding the consequences for child education, Zhang and Xu (2016) analysed the impacts of drinking water program on youth education attainment in rural China based on the China Health and Nutrition Survey conducted in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009 and 2011. Controlling for the county–year fixed effect, the estimated results show that the program significantly contributes to an increase in rural youth's completed schooling grades, with girls benefiting more than boys. Consistent with Augsburg and Rodríguez-Lesmes (2018), the youths with access to treated water in early childhood achieve significantly larger gains in education attainment, compared with the other youths gaining access at later stages of life. Choudhuri and Desai (2021) adopts Heckman selection and the entropy balancing method with the second round of the India Human Development Survey (2011–12) to evaluate the effects of access to piped water on child education in rural India. The findings show that the piped water helps improve children's education such as mathematics scores. Nonetheless, the most recent study by Frempong et al. (2021) found, consistent with the studies by Pattanayak et al. (2007), Clasen et al., (2014), and Patil et al., (2014), that the symptoms of individuals' illness is unlikely associated with the inadequate water supply in Uganda (Frempong et al., 2021).

Although the impacts of safe water on health and education outcomes were extensively evaluated by many studies, the implications of piped water for household food consumption have been scantly quantified. Furthermore, the results from the studies on the assessment of safe water on education and health remain seemingly inconclusive. The analysis of effects on household food consumption is, hence, worth being performed to provide further evidence for policy toward improving livelihoods, ensuring food security and nutrition, and reducing poverty, in such particular case as Cambodia where the empirical study is limited. Moreover, the evaluation of potential mechanisms underlying the effects on household food consumption is also scant.

3. Analytical Framework

The study mainly quantifies the effects of piped water on household consumption per capita by adopting treatment effects approaches to address econometric challenges such as endogeneity. The effects on household productivity in terms of primary household income per working-age member are also estimated to give more insights into the potential consequences of piped water.

3.1. Inverse-probability-weighted regression adjustment (IPWRA) approach

The simplest method to evaluate the impacts would be to incorporate a dummy variable equal to 1 if the household adopt piped water and zero otherwise into food consumption equation as an independent variable and then to estimate the equation with ordinary least squares (OLS). However, this procedure may yield biased and inconsistent results because the decision to use piped water is potentially endogenous. Moreover, the decision is voluntarily made and may be based on individual households' self-selection. Addressing the endogeneity of the decision, IV approach can be used. However, it is hard to apply this method because there is no appropriate theoretical guidance and the unavailability of any appropriate instrument from the dataset.

To address these challenges, the IPWRA approach has potential advantage over IV methods because it estimates the treatment effects without instrument restriction, and the treatment probability is estimated without assuming the functional form of the outcomes (Seng, 2021). The concept of IP weighting is to estimate the treatment model (i.e., the decision to use piped water) and predict the treatment, then assign the inverse treatment probability for treated individuals and that for untreated individuals (i.e., control individuals). The effects can be estimated with the outcome model using these new weights. Although either treatment or outcome is mis-specified, the estimators are still consistent due to the IPWRA estimators' double-robust property. The probit model is adopted to estimate the decision to use piped water with the following specification:

$$P_i = Pr(D_i = 1) = \alpha Z_i + u_i \qquad (1)$$

where P_i is the probability of using piped water. D_i represents whether household i decides to use or not to piped water. Z_i is the set of covariates associated with the decision. α and u_i are the coefficients to be estimated and error term, respectively. Using the propensity score predicted from Eq. 1, the weights can be derived as $w_i = \frac{D_i}{\hat{P_i}} + \frac{1-D_i}{1-\hat{P_i}}$.

An individual's weight represents the inverse probability of using piped water, with the users being assigned the weight $1/\widehat{P}_i$ and the nonusers being assigned the weight of $1/(1-\widehat{P}_i)$.

Nevertheless, because the effects are estimated conditionally on weighted propensity score, the balancing-covariates property needs to be satisfied to ensure that there is no structural differences in covariates between the treated and untreated groups. The endogeneity of the decision to use piped water can be addressed if: first, the conditional independence is hold, demonstrating that the assignment is not dependent on food consumption conditional on observed characteristics; and second, the propensity score of using piped water must range between 0 and 1. In this case, the covariates' balancing property must be checked with a statistical testing.

Following the previous studies using techniques of weighting via the propensity score in estimating causal treatment effects (e.g., Robins, Rotnitzky, & Zhao, 1994; Hirano, Imbens, & Ridder, 2003; Lunceford & Davidian, 2004), the average treatment effects (ATE) of using piped water on food consumption can be estimated by:

$$ATE = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{D_i Y_i}{\widehat{P}_i(Z_i)} - \frac{(1-D_i)Y_i}{1-\widehat{P}_i(Z_i)}\right] \tag{2}$$

where Y_i is household i's food consumption per capita, n represents the number of households. Observations with high $1/\widehat{P}_i(Z_i)$ in the treatment group are weighted down when treated and then weighted up when untreated. The opposite happens for observations with low $1/\widehat{P}_i(Z_i)$.

3.2. Endogenous treatment effects (ETE) model

There is still a concern over unobservable confounders that are likely to affect both the treatment and outcome. For example, households'/individuals' health awareness would determine the decision to use piped water and spend more on food consumption. In this case, the conditional independence assumed in the IPWRA approach is unsatisfied, yielding biased and inconsistent estimates. Accounting for the unobservable confounders, the ETE model is more appropriate to address the endogeneity problem with a control-function approach (Wooldridge, 2015). In the ETE model, the observed binary treatment and outcomes can be specified as follows:

$$D_i = E(D_i|Z_i) + u_i \tag{3}$$

$$Y_i = D_i Y_{i1} + (1-D_i)Y_{io} \tag{4}$$

where D_i is the observed treatment corresponding to household i's decision to use piped water, Y_i is the observed outcomes. Z_i is covariates associated with the decision. u_i is error term assumed to follow $u_i \sim N(0,1)$. The potential outcome of receiving the treatment Y_{i1} (using piped water) and the potential outcome when the treatment is not received Y_{io} (do not using piped water) can be expressed as follows:

$$Y_{i1} = E(Y_{i1}|X_i) + v_{i1} \tag{5}$$

$$Y_{i0} = E(Y_{i0}|X_i) + v_{i0} \tag{6}$$

$$E(v_{ij}|X_i, Z_i) = E(v_{ij}|Z_i) = E(v_{ij}|X_i) = 0 \; for \; j \in \{0,1\} \tag{7}$$

$$E(v_{ij}|D_i) \neq 0 \; for \; j \in \{0,1\} \tag{8}$$

Individual potential outcomes are determined by the expected value conditional on a set of covariates X_i and an unobserved random component v_{ij} for $j \in \{0,1\}$. Similarly, the treatment is given by its expectation conditional on a set of covariates Z_i that does not necessarily differ from X_i, and an unobserved component u_i.

Eqs. (3)–(7) describe the parametric treatment-effects models. Eq. (8) incorporates the endogeneity into the framework, indicating the correlation between the unobserved confounders such as health consciousness in the potential-outcome equations and the treatment status. This unobserved factor would affect both the decision to use piped water and food consumption and even income per working-age member.

Eqs. (3), (7), and (8) are the basis of the control-function estimator (e.g., Cerulli, 2014). Eq. (7) reveals that the unobserved confounders in the potential outcomes are independent of Z_i, suggesting that the correlation between D_i and the unobserved confounders is indicated by the correlation between v_{ij} and u_i. These can be derived from Eqs. (3) and (7) as follows:

$$E\left(v_{ij}\middle|D_i\right) = E\left(v_{ij}\middle|E(D_i|Z_i) + u_i\right) = E\left(v_{ij}\middle|u_i\right) = u_i\beta_{2j} \tag{9}$$

The treatment equation describing the decision to use piped water in Eq. (3) is estimated with a probit model. $\widehat{u_i}$ is, then, derived as the difference between the treatment and our estimate of $E(D_i|Z_i)$ and is used to calculate an estimate of $E(Y_{ij}|X_i, u_i, D_i)$ for $j \in \{0, 1\}$. The linear outcome can be derived as follows:

$$E\left(Y_{ij}\middle|X_i, u_i, D_i = j\right) = X_i\beta_{1j} + u_i\beta_{2j} \text{ for } j \in \{0, 1\} \tag{10}$$

The parameters of Eqs. (3) and (12), potential-outcomes means (POMs) and ATE can be estimated with the generalized method of moments (GMM). The moment equations in the GMM are the sample analogs of $E\left(W_i v_i(\omega)\right) = 0$, where W_i is the instruments, $v_i(\omega)$ is residuals with ω being the parameters of the model.[1] The ETE is estimated with a control-function approach using the average village distance to piped water supply sources as the instrument restriction. This approach is more effective in estimating the ATE (Wooldridge, 2015). It accounts for the endogeneity by incorporating the residuals $v_i(\omega)$ derived from the treatment model as a regressor in the outcome function. Furthermore, the endogeneity, resulted from unobserved confounders, can be tested with a null hypothesis that the unobserved confounders of the treatment and outcome are uncorrelated. The rejection of the hypothesis confirms that the ETE model is more appropriate than IPWRA.

4. Data Sources and Variables

This section describes the source of data and main variables used in the analysis. A descriptive statistical analysis is also presented at the end of the section, with simple statistical tests of differences in means.

4.1. Data used in the analysis

The data from the CSES surveyed in 2013 and 2017 by the National Institute of Statistics (NIS) are used for the analysis. The CSES is a comprehensive survey which represents the nationwide sample, with statistical data being utilised for various purposes. The 2013 and 2017 CSESs sample a total of 3600 households and 3840 households, respectively, within 384 villages representing 25 provinces (all provinces in Cambodia). The NIS has performed the CSES survey since 2004, depending on national budget for the survey. However, due to the limited budget to have access to all available CSESs, only the 2013 and 2017 CSESs are in this study. Nonetheless, some households did not provide full information on the variables of interest, thus there are missing observations. Adjusting for missing observations, the final sample counts are 3352 and 3333 households in 2013 and in 2017, respectively, in the regression analysis. Furthermore, a village-panel data is constructed to provide a robustness analysis by addressing time-invariant unobservable heterogeneity problems.

[1] Further detail on deriving ETE model, POMs, ATE and the moment conditions in the GMM estimation can be found in StataCorp (2015).

4.2. Variables

The dependent variable used in the treatment equation is a binary variable for the use of piped water. The dependent variable in the outcome equation are the household food consumption per capita and household productivity measured by primary income per waking-age member.

The explanatory variables consist of household head's characteristics, household characteristics, average village water spending and average village distance to piped water supply sources. The head's characteristics include age, completed schooling years, and ethnicity. These characteristics are expected to determine the decision to use piped water (Augsburg & Rodríguez-Lesmes, 2018; Choudhuri & Desai, 2021; O'Gorman, 2021) and affect household food consumption and household productivity (Imai, Arun, & Annim, 2010; Imai & Azam, 2012; Seng, 2018; Seng, 2021). The heads are also grouped into two categories according to marriage status – single and married. In a similar fashion, the heads' occupations are categorised according to their employment status – employee and own account. These characteristics are also likely to determine the food consumption and productivity (Imai, Arun, & Annim, 2010; Imai & Azam, 2012; Seng, 2018). These household characteristics, captured by household members under 15 years of age, members over 64 years of age, working-age members, and a dummy for households settling in rural area, are expected to affect both the decision to use piped water (Augsburg & Rodríguez-Lesmes, 2018; Choudhuri & Desai, 2021; O'Gorman, 2021) and outcomes (Imai, Arun, & Annim, 2010; Imai & Azam, 2012; Seng, 2018). The average village water spending is also very likely to determine the decision to use piped water and then food consumption because the higher spending is likely to discourage households from using the piped water by choosing other sources and reduce the spending on food consumption, then affecting household labour productivity. The average village distance to piped water supply sources is also likely to affect the decision to use piped water because it affects the time of collecting/connecting water (e.g., Frempong, Kitzmüller, & Stadelmann, 2021). Because it is likely to increase the time of collecting/connecting water, the longer distance is likely to discourage households from using piped water. The definition of these variables is summarised in Table A1.

4.3. Descriptive Statistics

On average, the households spent approximately US$10 and US$13 in 2013 and 2017, respectively, on per capita food consumption per week. Moreover, on average, the households enjoyed weekly primary income per working-age member of approximately US$21 and US$40 in 2013 and 2017, respectively. From 2013 to 2017, the percentage of using piped water increased from approximately 34 per cent to 41 per cent. These results indicate that alongside a percentage growth in the use of piped water, the household livelihood is likely to get improved from 2013 to 2017. Further detail on the data on other variables can be found in Table A2.

The results of descriptive statistical analysis in Table 1 demonstrate that the households using piped water accounted for approximately 51 per cent and 70 per cent in 2013 and 2017, respectively, suggesting an improvement in household access to piped water. Furthermore, Table 1 illustrates some significant and non-significant differences in mean of each variable between household users of piped water and nonusers, confirmed by simple statistical tests. In particular, on average, the weekly food consumption per capita enjoyed by the users was approximately US$4 and US$4.5 in 2013 and 2017, respectively, as significantly high as that enjoyed by the nonusers. Likewise, on average, the weekly primary income per working-age member enjoyed by the users was approximately US$8 and US$18 in 2013 and 2017, respectively, as significantly high as that enjoyed by the nonusers. These results suggest that the gains made by the users are likely to get larger from 2013 to 2017 in terms of household food consumption and primary income per capita. However, it does not necessarily mean that the use of piped water has the food-increasing and income-generating effects on households due to such technical problem as the endogeneity of the household decision to use piped water. Such a problem cannot be addressed by this simple statistical comparison method.

Table 1. Household characteristics by piped water usage status.

	2013					2017				
	Users (N=1290)		Nonusers (N=2550)		Differences in Mean	Users (N=1587)		Nonusers (N=2253)		Differences in Mean
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Food[a]	12.68	5.47	8.88	4.22	3.80***	15.53	8.59	11.07	5.28	4.47***
Income[b]	25.74	13.78	18.14	10.50	7.60***	50.73	52.90	32.90	53.99	17.83***
Head's age	49.14	12.89	46.71	13.91	2.42***	50.02	13.28	48.65	14.00	1.37***
Head's gender	0.78	0.42	0.79	0.41	-0.01	0.24	0.43	0.22	0.42	0.01
Single	0.02	0.14	0.02	0.13	-0.001	0.02	0.14	0.01	0.11	0.01*
Married	0.78	0.42	0.80	0.40	-0.02	0.76	0.43	0.78	0.41	-0.02*
Head's ethnicity	0.98	0.13	0.98	0.13	-0.001	0.96	0.20	0.98	0.15	-0.02***
Head's educa.	7.89	4.64	4.91	3.64	2.97***	7.43	5.01	4.62	3.92	2.81***
Employee	0.46	0.50	0.29	0.45	0.17***	0.52	0.50	0.34	0.47	0.18***
Own business	0.53	0.50	0.71	0.46	-0.18***	0.48	0.50	0.65	0.48	-0.18***
Member < 15	1.04	1.08	1.36	1.21	-0.32***	1.03	1.10	1.31	1.17	-0.28***
Member > 64	0.24	0.53	0.23	0.52	0.01	0.27	0.55	0.28	0.57	-0.01
Working-age	3.20	1.49	2.90	1.42	0.31***	3.06	1.48	2.85	1.42	0.20***
Rural	0.18	0.39	0.85	0.36	-0.67***	0.23	0.42	0.85	0.35	-0.62***
Distance	45.46	20.07	47.78	23.44	-2.32***	29.99	12.69	31.43	19.02	-1.44***
Water spending	2.95	0.96	2.59	0.98	0.36***	3.68	0.90	3.43	0.83	0.25***

*Notes: [a] Weekly household food consumption spending per capita in US dollar. [b] Weekly household primary income per working-age member in US dollar. * denotes test statistic significance at 10 per cent level. *** denotes test statistic significance at 1 per cent level.*

Moreover, with an average of approximately 8 and 7 of completed schooling years in 2013 and 2017, respectively, the education levels of the piped water users' heads were significantly higher than those of the nonusers' heads, with an average of approximately 5 and 4 of completed schooling years in 2013 and 2017, respectively. The results illustrate that the household heads' education levels are likely one of the main factors potentially determining the household decision whether to use piped water or not to use. Further detail on the differences in mean between the piped water users and the nonusers in terms of other variables can be found in Table 1.

5. Results and Discussion

The descriptive statistical analysis indicates the significant differences in household food consumption per capita and income per working-age between the users and the nonusers. The econometric analysis is further performed to quantify the effects of piped water on households, addressing endogeneity issues concerning the decision to use piped water.

5.1 Determinant of decision to use piped water

Table 2 reports the estimated results of the probit models describing the household decision to use piped water. The results suggest that the Khmer-headed households are likely to reduce the likelihood of using piped water, in particular in 2017, probably because they prefer such other water sources as river and water well. Other possible reasons are their traditional habit of using water, especially those in the out-of-the-way areas, and health awareness of the advantage of using safe water and water sanitation. Moreover, the households settling in rural communities are likely to reduce the probability of using piped water in both 2013 and 2017. These results can explain the fact that people living in the rural areas are likely to prefer traditional water sources to piped water, more probably because the piped water supply in the rural localities remains limited with higher costs. Furthermore, the majority of rural households have limited understanding of the health advantage of using piped water, then more unlikely to be interested in piped water.

Table 2. Determinants of household decision to use piped water

Variables	2013			2017		
	Coef.	SE	*p*-value	Coef.	SE	*p*-value
Head's age	0.046	0.037	0.213	0.047**	0.022	0.031
Head's age squared	0.0001	0.000	0.263	0.0001**	0.000	0.041
Head's gender	0.102	0.102	0.319	0.003	0.097	0.973
Single	-0.052	0.131	0.694	0.043	0.295	0.884
Married	-0.120	0.102	0.239	0.072	0.112	0.518
Head's ethnicity	-0.549	0.402	0.172	-0.654***	0.088	0.000
Head's education	0.015	0.039	0.710	0.011	0.023	0.628
Head's edu. squared	0.003	0.003	0.339	0.002	0.002	0.237
Employee	-0.233	0.485	0.631	0.443	0.281	0.114
Own business	-0.416	0.501	0.406	0.240	0.273	0.380
Member under 15	-0.081	0.051	0.114	-0.030	0.027	0.273
Member over 64	-0.009	0.069	0.892	-0.016	0.093	0.866
Working-age member	-0.028	0.036	0.438	-0.048	0.044	0.273
Rural	-1.785***	0.121	0.000	-1.615***	0.082	0.000
Distance	-0.009***	0.002	0.000	-0.004***	0.001	0.002
Water spending	-0.143***	0.036	0.000	-0.130***	0.045	0.004
Constant	0.247	1.157	0.831	-0.531	0.644	0.410
Observations	3352			3333		

*Notes: The results are estimated with probit model. SE is the robust standard error. ** denotes test statistic significance at 5 per cent level. *** denotes test statistic significance at 1 per cent level.*

As expected, the coefficients on the average distance from house to water sources at the village levels are significantly negative, in both 2013 and 2017, suggesting that the longer the distance the lower the probability that households are induced to use piped water. Furthermore, the coefficient of average spending on water at the village levels is significantly negative, suggesting the negative correlation with the decision to use piped water. An increase in spending on water reduces the probability that households use piped water.

5.2. Effects of piped water on household consumption and income

Table 3 presents the IPWRA results of potential means of food consumption and primary income per working-age member under actual and counterfactual conditions as well as the average treatment effects (ATE), with the first 4 rows corresponding to the household food consumption and the second 4 rows corresponding to the household income.

In 2013, the potential food consumption mean is approximately US$11.5 when the household uses piped water, and approximately US$9.76 when the household does not use. The estimated result indicating the significant ATE of approximately US$1.74 per week demonstrates that, once using piped water, the household can make US$1.74 weekly food consumption gain per household member. In a similar fashion, in 2017, the potential food consumption mean is approximately US$13.72 when the household uses piped water, and approximately US$12.50 when the household does not use, illustrating that the piped water household can make US$1.25 weekly food consumption gain per capita. These results suggest that the piped water is likely to help increase household food consumption per capita.

Regarding the income per working-age member, in 2013, the potential income mean is approximately US$23.71 when the household uses piped water, and approximately US$20 when the household does not use. The estimated result indicating the significant ATE of approximately US$3.6 per week suggests that, when using piped water, the household can make a weekly income gain by approximately US$3.6 per working-age member. In a similar fashion, in 2017, the potential income mean is approximately US$48 when the household uses piped water, and approximately US$38 when the household does not use, illustrating that the household can make a weekly income gain by approximately US$10 per working-age member. These results reveal that the piped water is likely to promote labour productivity. The improvement in productivity helps promote household earnings, then increasing household food consumption.

Table 3. Effects of piped water on household consumption and labour income (IPWRA).

	2013[a]			2017[b]		
	POM	SE	*p*-value	POM	SE	*p*-value
Food consumption						
Use	11.503***	0.230	0.000	13.715***	0.192	0.000
Not use	9.760***	0.118	0.000	12.469***	0.232	0.000
ATE	1.743***	0.251	0.000	1.246***	0.286	0.000
Income per working-age						
Use	23.706***	0.520	0.000	48.025***	1.762	0.000
Not use	20.083***	0.303	0.000	38.020***	1.517	0.000
ATE	3.623***	0.588	0.000	10.005***	2.310	0.000

Notes: Food consumption is the weekly household food consumption spending per capita in US dollar. Income per working-age is the weekly household primary income per working-age member in US dollar. POM denotes potential outcome mean. SE is the robust standard error. [a] Overidentification test for covariate balance shows that the null hypothesis that covariates are balanced is rejected, evidenced by $\chi^2 = 29.82$ *and* $Prob > \chi^2 = 0.028$. *[b] Overidentification test for covariate balance indicates that the null hypothesis that covariates are balanced is rejected, confirmed by* $\chi^2 = 27.349$ *and* $Prob > \chi^2 = 0.053$. **** denotes test statistic significance at 1 per cent level.*

However, in the estimation of ATE for the weekly household food consumption per capita, the overidentification test for covariate balance reported at the bottom of Table 3 demonstrates that the balancing-covariates property is unsatisfied. The endogeneity of the decision to use piped water cannot be addressed by the IPWRA, without the conditional independence and the propensity score of using piped water ranging between 0 and 1 being hold. The unobserved confounders such as households'/individuals' health awareness would determine both the decision to use piped water and the spending on food consumption, yielding biased and inconsistent estimates. Accounting for such an unobserved confounder, the ETE model is adopted and estimated with the control-function approach.

Table 4. Effects of piped water on household consumption and labour income (ETE).

	2013[a]			2017[b]		
	POM	SE	p-value	POM	SE	p-value
Food consumption						
Use	24.125***	4.978	0.000	28.695***	5.162	0.000
Not use	8.425***	0.307	0.000	5.882***	1.858	0.002
ATE	15.700***	4.672	0.001	22.813***	5.479	0.000
Income per working-age						
Use	40.521***	10.689	0.000	70.908***	3.074	0.000
Not use	20.551***	0.346	0.000	44.677***	1.009	0.000
ATE	19.970*	11.035	0.070	26.231***	2.065	0.000

*Notes: The estimation excludes the average village distance from the treatment equation. Food consumption is the weekly household food consumption spending per capita in US dollar. Income per working-age is the weekly household primary income per working-age member in US dollar, measuring household labour productivity. POM denotes potential outcome mean. SE is the robust standard error. [a] The tests of endogeneity for the decision to use piped water indicate that the null hypothesis that treatment and outcome unobservables are uncorrelated is rejected, confirmed by $\chi^2 = 12.660$ and $Prob > \chi^2 = 0.002$ and $\chi^2 = 3.280$ and $Prob > \chi^2 = 0.070$, for food consumption per capita and income per working-age member, respectively. [b] The tests of endogeneity for the decision to use piped water demonstrate that the null hypothesis that treatment and outcome unobservables are uncorrelated is rejected, supported by $\chi^2 = 20.010$ and $Prob > \chi^2 = 0.000$ and $\chi^2 = 36.770$ and $Prob > \chi^2 = 0.000$, for the food consumption and income, respectively. * denotes test statistic significance at 10 per cent level. *** denotes test statistic significance at 1 per cent level.*

Table 4 presents the ETE results, with the first 4 rows corresponding to the food consumption per capita and the second 4 rows corresponding to the income per working-age member. The results reported at the bottom of Table 4 suggest that the null hypothesis that treatment and outcome unobserved confounders are uncorrelated is rejected for food consumption per capita and income per working-age member in both 2013 and 2017. These results reveal that there is the presence of unobserved confounders. Then, the ETE approach is more appropriate for addressing these challenges.

In 2013, the results illustrate that the estimated ATEs for food consumption and income are approximately US$15 per week and US$20 per week, respectively, for the use of piped water. Had the ATE been estimated ignoring the unobserved confounders causing the earlier mentioned endogeneity with the IPWRA approach, the ATEs for food consumption and income would have been US$1.74 and US$3.62, respectively. In a similar manner, in 2017, estimated ATEs for food consumption and income are approximately US$23 per week and US$26 per week, respectively, for the use of piped water, which are much higher than the IPWRA ATEs (i.e., US$1.23 and US$10). These estimated results show that the under-estimation of the effects by the IPWRA arises from the unobserved confounders. The ETE results suggest that the piped water is very likely to increase household income per working-age member and per capita food consumption. The access to piped water is very likely to promote household health, as evidenced by the recent studies (e.g., Augsburg & Rodríguez-Lesmes, 2018; O'Gorman, 2021, Frempong et al., 2021). Because the healthier people are likely to enjoy higher labour productivity (e.g., Strauss, 1986; Thomas & Strauss, 1997), they would enjoy higher earnings and then spend more on food consumption.

5.3. Village-level robustness

The village-panel data is also constructed to check the robustness of the IPWRA and ETE results. Some covariates are highly likely to be correlated with time-invariant unobservable heterogeneity at the village levels. This challenge cannot be controlled by either IPWRA or ETE models but can be addressed with an alternative fixed-effects approach. Following Frempong, Kitzmüller and Stadelmann (2021), the outcomes (i.e., food consumption per capita and income per working-age member) can be specified as follows:

$$Y_{jt} = \beta Z_{jt} + \alpha_v + \lambda_t + \gamma C_{jt} + \varepsilon_{jt} \tag{11}$$

where Y_{jt} is the outcome in village *j* and year *t*, α_v represents village-fixed effects, C_{jt} is controlling variables village *j* and year *t*, λ_t represents time-fixed effects, and ε is error term. β is the parameter to be estimated, capturing the effects of usage of piped water on outcomes. All dependent and independent variables represent the average village levels.

Table 5 presents the estimated results of the effects of piped water on household food consumption per capita. The OLS results suggest the nonsignificant effects of the piped water on food consumption. Controlling for village fixed-effects, the FE results show that the coefficient of piped water is significantly positive, consistent with the ETE results of the favourable effects on household food consumption per capita. Moreover, when fixing both the village and period effects, the coefficient remains significantly positive at the same level, with a smaller magnitude from (i.e., from 7.4 in OLS model to 6 in FE model).

Table 6 presents the estimated results of the effects of piped water on household income per working-age member. In Table 6, the OLS results suggest the nonsignificant and negative effects of the piped water on income. Controlling for village fixed-effects, the FE results demonstrate that the coefficient of piped water become significantly positive, confirming the ETE results reported in Table 5 that illustrate the desirable effects on household income per working-age member. Furthermore, when both the village and period effects are simultaneously fixed, the coefficient remains significantly positive at the same level, with a larger magnitude (i.e., from 34 in OLS model to 40 in FE model).

Table 5. Effects of piped water on household consumption per capita.

	Ordinary Least Squared (OLS)			Fixed Effects (FE)					
Variables	Coef.	SE	*p*-value	Coef.	SE	*p*-value	Coef.	SE	*p*-value
Piped water	0.06	1.86	0.98	7.40**	2.63	0.03	6.01**	2.00	0.02
Head's age	-0.88	0.85	0.31	0.31	1.02	0.77	0.73	0.80	0.40
Head's age squared	0.01	0.01	0.25	0.00	0.01	0.83	-0.01	0.01	0.38
Head's gender	-5.34***	0.88	0.00	-4.09***	0.86	0.00	-3.01**	1.02	0.03
Single	14.13	8.66	0.11	5.21	9.67	0.61	8.77	9.31	0.38
Married	-2.57	3.01	0.40	-3.86	4.00	0.37	-7.55	4.39	0.14
Head's ethnicity	1.28	6.39	0.84	5.64	7.53	0.48	2.19	5.32	0.70
Head's education	0.65	0.98	0.51	0.69	0.90	0.47	-0.18	0.66	0.79
Head's edu. squared	0.03	0.06	0.58	-0.01	0.07	0.92	0.07	0.06	0.29
Employee	43.97**	20.36	0.04	166.9***	27.83	0.00	164.1***	24.43	0.00
Own business	42.27**	20.15	0.04	160.0***	26.69	0.00	156.8***	23.96	0.00
Member under 15	-0.34	0.80	0.67	-1.51	0.80	0.10	-2.46*	1.06	0.06
Member over 64	-9.91**	3.76	0.01	-5.40	3.28	0.14	-2.44	2.97	0.44
Working-age member	-0.41	0.50	0.42	-4.38**	1.64	0.03	-5.24**	1.31	0.01
Rural	-2.50	1.61	0.13	-5.81**	1.89	0.02	-2.59	4.20	0.56
Water spending	-0.35**	0.15	0.02	-0.87***	0.19	0.00	-0.76**	0.20	0.01
Village				Yes			Yes		
Year				No			Yes		
Constant	-9.73	24.49	0.69	-143.98	42.19	0.01	-139.5**	34.01	0.01
Observations	48			48			48		
Adjusted R-squared	0.86			0.92			0.92		
Cross-section fixed effects test				$\chi^2 = 97.79$		0.00			
Cross-section and period fixed effects test							$\chi^2 = 104.67$		0.00

*Notes: * denotes test statistic significance at 10 per cent level. * denotes test statistic significance at 5 per cent level. *** denotes test statistic significance at 1 per cent level.*

The fixed-effects results consistent with the ETE results, suggesting that the results of the estimated effects of piped water on household food consumption and household income per working-age member are robust. Thus, the sufficient access to piped water and promoting the health awareness of the advantage of piped water, in rural communities in particular, can help increase labour income and food consumption, ensuring household food security.

6. Conclusion

The majority of empirical studies quantify the effects of access to safe water on child education and health outcomes, knowledge remains limited concerning the consequences of piped water for household food consumption. The sufficient food consumption for people is the main pathway to improving their livelihoods, ensuring their food security and nutrition, and reducing poverty, in out-of-the-way communities in particular. Understanding the potential of improving food consumption through access to safe water is of food security and poverty alleviation policy relevance.

This study analyses the effects of piped water on household food consumption per capita in Cambodia by using IPWRA and ETE approaches with the Cambodia Socio-Economic Survey conducted in 2013 and 2017. A complementary analysis of the effects on primary household income per working-age member is also conducted to give insights into the potential effects on household food consumption. Because the sufficient and safe water is one of the main factors determining the productivity of labour, access to piped water is likely to improve household earnings and food consumption. The robust results from IPWRA and ETE approaches suggest that households that use piped water can make gains in terms of food consumption per capita and income per working-age member.

Table 6. Effects of piped water on income per working-age member.

	Ordinary Least Squared (OLS)			Fixed Effects (FE)					
	Coef.	SE	*p*-value	Coef.	SE	*p*-value	Coef.	SE	*p*-value
Piped water	-5.33	5.41	0.33	34.02**	14.69	0.05	40.11**	15.47	0.04
Head's age	-12.3***	2.28	0.00	3.70	5.18	0.50	1.87	6.47	0.78
Head's age squ.	0.13***	0.02	0.00	-0.04	0.05	0.47	-0.02	0.07	0.82
Head's gender	-35.9***	2.71	0.00	-26.7***	3.34	0.00	-31.4***	6.53	0.00
Single	-84.21**	40.24	0.04	-144.2***	33.82	0.00	-159.7**	38.83	0.01
Married	-6.47	10.12	0.53	16.54	14.74	0.30	32.69	22.20	0.19
Head's ethnicity	-19.85	34.60	0.57	28.91	49.49	0.58	44.02	38.54	0.30
Head's edu.	1.28	3.00	0.67	-5.85	5.40	0.32	-2.04	5.19	0.71
Head's edu. squ.	0.03	0.19	0.88	0.28	0.39	0.51	-0.08	0.43	0.86
Employee	-71.76	81.96	0.39	606.82***	136.21	0.00	618.0**	144.22	0.01
Own business	-73.53	81.98	0.38	598.73***	131.49	0.00	613.1***	139.05	0.00
Member < 15	8.66**	3.21	0.01	-3.75	4.82	0.46	0.42	6.53	0.95
Member > 64	-34.6***	8.68	0.00	19.45	15.35	0.25	6.52	21.48	0.77
Working-age	13.01***	2.25	0.00	-7.18	6.31	0.29	-3.42	8.50	0.70
Rural	-22.69***	4.78	0.00	-37.60**	10.42	0.01	-51.7***	18.88	0.03
Water spending	-0.95*	0.48	0.06	-3.35***	0.82	0.00	-3.87**	0.98	0.01
Village				Yes			Yes		
Year				No			Yes		
Constant	389.83***	77.00	0.00	-610.94**	216.98	0.03	-630.6**	245.52	0.04
Observations	48			48			48		
Adjusted R^2	0.84								
Cross-section fixed effects test				$\chi^2 = 64.34$		0.00			
Cross-section and period fixed effects test							$\chi^2 = 72.00$		0.00

*Notes: * denotes test statistic significance at 10 per cent level. * denotes test statistic significance at 5 per cent level. *** denotes test statistic significance at 1 per cent level.*

The robustness analysis with the village panel data also confirm these desirable results, revealing that the piped water is very likely to increase the household food consumption and income per capita. Arguably, the favourable impacts of piped water on household food consumption can explain the fact that the piped water contributes to households' health improvement that helps increase labour productivity. The improved productivity is the most significant factor boosting household earnings. Therefore, promoting the access to piped water and the health awareness of the advantage of using piped water, for people in remote communities in particular, can increase labour productivity and food consumption, which are the best way of improving household food security and helping fighting poverty in rural communities.

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Conflict of interest

The author claims that the manuscript is completely original. The author also declares no conflict of interest.

Appendix

Table A1. Summary of variables.

Variables	Definition
Dependent	
- Household food consumption per capita	Weekly household spending on food consumption per household member
- Household labour productivity	Weekly household primary income (i.e., income from agricultural, own account and employment) per working-age household member
- Piped water	=1 if the household uses tap water connected with the distribution lines of a piped water supply station
Independent	
- Head's age	Natural log of household head's age in years
- Head's gender	=1 if the household is headed by woman
- Single	=1 if the head is single
- Married	=1 if the head is married
- Head's ethnicity	=1 if the head is Khmer
- Head's education level	Head's years of completed schooling
- Employee	=1 if the head is employee
- Own business	=1 if the household works for his/her own account
- Member under 15	The number of household member under 15 years of age
- Member over 64	The number of household member over 64 years of age
- Working-age member	The number of household member from 15 years of age to 64 years of age
- Rural	=1 if the household settles in rural area
- Distance	Average village distance in metre to piped water supply sources
- Water spending	Average village water spending

Table A2. Summary of descriptive statistics.

	2013				2017			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Food consumption	10.16	5.01	2	78	12.91	7.19	3	125
Income per working-age	20.69	12.24	0	133	40.27	54.25	0	1770
Piped water	0.34	0.47	0	1	0.41	0.49	0	1
Head's age	47.53	13.62	15	88	49.22	13.72	19	93
Head's gender	0.79	0.41	0	1	0.23	0.42	0	1
Single	0.02	0.14	0	1	0.02	0.12	0	1
Married	0.79	0.41	0	1	0.78	0.42	0	1
Head's ethnicity	0.98	0.13	0	1	0.97	0.17	0	1
Head's education	5.91	4.24	0	23	5.78	4.62	0	20
Employee	0.35	0.48	0	1	0.41	0.49	0	1
Own business	0.65	0.48	0	1	0.58	0.49	0	1
Member under 15	1.25	1.18	0	8	1.19	1.15	0	7
Member over 64	0.24	0.52	0	3	0.28	0.56	0	3
Working-age member	3.00	1.45	0	9	2.94	1.45	0	13
Rural	0.63	0.48	0	1	0.60	0.49	0	1
Distance	47.00	22.39	7	183	30.83	16.71	12	182
Water spending	2.71	0.98	0	8	3.54	0.87	1	9

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