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Combining averting expenditure and contingent valuation to evaluate the loss of water outage in residential sector and its application

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Abstract: Most previous studies on water disruption losses focus on the industrial sectors. This paper aims to estimate the loss in the residential sector due to water outages. Three focus group discussions with 42 household representatives who experienced a water outage ranging from 1 to 3 weeks after the 2016 Meinong Earthquake in Southern Taiwan were held and individual surveys were conducted. The averting expenditure approach was adopted to compare the household expenditure for various types of water usage during the water outage with that for the normal situation. The willingness-to-accept (WTA) compensation for the inconvenience of resorting to other water sources was evaluated. The evaluation revealed that the loss to a household due to a water outage day accounted for up to 15% of the household's monthly income and had a mean of 1008 NTD (34 USD). The loss as a proportion of income was the highest in households with children and elderly. The loss due to a water outage in the residential sector can be used in the cost-benefit analysis of water shortage mitigations including additional water sources, pipeline system enhancement, and water demand management.

Key words: Residential sector; water outage; contingent valuation; averting expenditures

1. INTRODUCTION

Since Taiwan is located at the convergence of the Philippine and Eurasia plates and is characterized by high seismic activity, earthquakes can trigger water supply interruption due to pipeline breakages. An earthquake with a magnitude of 6.4, which at 03:57 a.m. (local time) on February 6th, 2016 hit southern Taiwan (Henry et al., 2017) caused serious damage to the pipeline system, leaving 400,000 households without access to tap water (Hu, 2017). The most affected were residents living in higher areas and whose houses were located at the ends of the pipeline system as the total reparation took more than two weeks (Hu, 2017). An extended lack of access to tap water causes severe inconveniences to residents as additional expenditures and time are required to gather water from different sources. Such situations could be avoided by reinforcing the water supply systems or by implementing new measures to provide other sources of water that could be accessed in emergencies. Both options are costly and require prudent cost-benefit analysis. This study, therefore, aims to propose a way to estimate the losses from water outages in the residential sector.

1.1 Loss of consumer surplus

The evaluation of the economic impacts of natural disasters has traditionally focused on businesses (Brozović et al., 2007; Rose and Guha, 2004). The methods applied in business loss estimations are not suitable, however, for the residential sector. The measurement of economic losses in a domestic context is much more difficult because of the lack of a monetary output (Brozović et al., 2007). According to Brozović et al. (2007), losses in the residential sector can be measured by the willingness to pay (WTP) to avoid water supply disruptions and that can be determined using different approaches, such as contingent valuation (CV), mathematical programming, and the integration of estimated demand curves. Jenkins et al. (2003) and Brozović et al. (2007) employed the estimated demand curves to measure the welfare (consumer surplus) losses of interrupted water supply in the residential sector. Jenkins et al. (2003) calibrated the data on the demand for water in California in 1995 to estimate the loss in 2020, using the constant price elasticity of demand. They estimated that the average annual loss caused by water scarcity of up to 50% could reach 1.6 billion USD in 2020. Brozović et al. (2007) appraised the loss of the complete water outage. They defined the restricted water quantity as the minimum recommended water requirements, which supposedly must be covered by governments in case of emergencies. Losses, therefore, are seen as the area between basic water requirements and regular water demand. According to their estimation, the residential losses from a water outage could be as high as US$279 million and US$37 million for the Andreas Fault (M 7.9) and Hayward Fault (M 7.1) earthquakes, respectively. The loss estimation methods adopted by Brozović et al. (2007) and Jenkins et al. (2003) require data on water consumption with price variations or price elasticity assumptions. The price of tap water in almost the whole of Taiwan is the same. Since the reliability of water supply in developed countries is usually very high, people's water consumption behavior could be very different as the result of a long period of water outage.

1.2 Contingent valuation method

Applying the contingent valuation method (CV) is a common way to measure the welfare losses caused by the changes in accessibility and/or quality of public goods (Hanemann, 1994). It is a survey-based method which can be presented in two forms: the willingness to pay (WTP) and the willingness to accept (WTA). WTP examines the consumers' readiness to pay more for an improvement in the quality and/or availability of a public good, while WTA examines the value that consumers would accept in case of theirs deterioration. Griffin and Mjelde (2000) examined the value of water supply reliability for more than 2,000 households in Texas, in a sample that included people with and without previous water shortfall experience. Hensher et al. (2006) studied the willingness to pay to avoid drought restrictions for 211 households and 205 businesses in Canberra, Australia where water supply is usually unrestricted (95% of the time), and restrictions appear at most every 20 years. Hatton MacDonald et al. (2010) applied WTA and WTP to assess the implicit value of water supply reliability in Adelaide, Australia. Groothuis et al. (2015) evaluated the willingness to pay for a single increment in taxes to support water conservation measures and ensure water supply stability during droughts in California in the U.S. Pietrucha-Urbanik and Studziński (2016) used the contingent valuation method as part of their analysis of water supply in Poland.

None of those studies, however, assessed the real and long-lasting water outage. All these works focused on water shortage, rather than a long-lasting water outage. There is no such charging program for improving water supply stability in the real world. According to economic theory, willingness to pay should almost equal willingness to accept compensation (Hanemann, 1994). The results of numerous studies, however, show that these values differ, and WTA significantly exceeds WTP (Hanemann, 1994; Hatton MacDonald et al., 2010). Although the National Oceanic and Atmospheric Administration's (NOAA) panel suggested using willingness-to-pay questions (Arrow et al., 1993), Carson (2000) pointed out that the choice between those two methods should be determined on the basis of property rights in relation to the good in question. In the situation where consumers do not own and do not have rights to the environmental good, it is appropriate to use WTP (Carson, 2000). In another case, when consumers have those entitlements but are required to give them up, WTA should be applied as consumers ought to be compensated (Carson, 2000; Hatton MacDonald et al., 2010). Pietrucha-Urbanik and Studziński (2016) emphasized the fact that water is a basic need good and, therefore, all users of the municipal water system should be ensured a certain amount and quality of water on the basis of the contract between the supplier and consumer. If the stated volume and quality parameters are not met, the recipient should have the opportunity to negotiate the final payment due to the inconveniences and indirect welfare losses.

1.3 Averting expenditures

The averting expenditures (or coping costs) method is one of the revealed preference (RP) methods. Such methods aim to examine the individual's existing choices to make inferences about the marginal benefits of similar improvements (Orgill-Meyer et al., 2018). Coping costs follow actions taken to lessen the impact of or avoid undesirable situations (Wu and Huang, 2001). In the case of insufficient water supply quantity or quality, such intervention may include spending time and money to look for alternative supply sources as well as additional treatments (Orgill-Meyer et al., 2018). Pattanayak et al. (2005) conducted research in Kathmandu, Nepal, where the majority of households have very limited access to clean tap water. As a result, residents gather water from additional sources, revealing an overall coping cost of approximately 1% of current income (3 USD per month). Orgill-Meyer et al. (2018) found that in Jordan, which continuously experiences a water scarcity problem, the average monthly coping costs account for some 4% of overall expenditures. It is important to note that in both cases residents revealed constraints regarding the quality of water. Therefore, coping costs aimed at improving quality were included in the estimation.

Freeman (1979) recognized an important limitation of the coping costs. This averting expenditures method assumes perfect substitution, which would mean that with some additional spending every unpleasant situation could be avoided. In the real world, however, such situations are extremely rare, and some disutility cannot be averted. It is therefore important to recognize those limitations, otherwise the cost-benefit analysis could lead to serious underestimates. Pattanayak et al. (2005) emphasized that even data on coping costs that are carefully collected are not able to fully cover all the costs related to "illnesses, work days and productivity losses, pain and suffering, and reduced leisure."

2. METHODS

Based on economic theory and previous studies, the WTP for improving water supply stability is the expected loss from a water outage. Since the service standard of alternative water sources may be lower than that for normal tap water, the averting expenditure during a water outage will be regarded as the lower bound estimation (Pattanayak et al., 2005; Wu and Huang, 2001). The inconvenience of reaching alternative water sources should be compensated (WTA). Since the WTA significantly exceeds the WTP, the averting expenditure plus the WTA will be regarded as the upper bound estimation of the loss of water outage. The loss per day due to the water outage can be calculated using the following 3 equations:

$$L = WTP \tag{1}$$

$$L = AE - WE_N \quad \text{(lower bound estimation)} \tag{2}$$

$$L = (AE + WTA) - WE_N \quad \text{(upper bound estimation)} \tag{3}$$

where WTP denotes the willingness-to-pay for a stable water supply; WE_N denotes water expenditure during a normal day; AE denotes the averting expenditure during the water outage; and WTA denotes the willingness-to-accept compensation for the inconvenience of making use of alternative water sources.

2.1 Expenditure estimation

The averting expenditures were assessed according to the "Hierarchy of Water Requirements" for medium-term emergencies, which includes: drinking, cooking, personal washing, washing clothes, cleaning home, growing food, sanitation and waste disposal (Reed et al., 2013). The cooking and growing food categories, however, were excluded from the analysis[1]. Based on the alternative water sources mentioned in the focus group discussions, the averting expenditures during the water outage were categorized into 4 usages in the personal questionnaire.

$$AE = E_D + E_S + E_L + E_O \tag{4}$$

where E_D denotes the household expenditure on drinking water; E_S denotes the household expenditure on personal washing and sanitation; E_L denotes the household expenditure on laundry; and E_O denotes the household expenditure on other activities requiring tap water.

Based on the way in which the respondents answered the questions as to how they paid for alternative water sources, such as buying bottled water, paying for water from a private water truck, having a rest in a hotel (in order to have a shower/bath), and washing clothes at a laundromat, the real expenditure was calculated. Some respondents could not specify their real expenditure. For example, they carried water from temporary water stations, had a shower and did their laundry in their friends' or relatives' homes, or used ground water. The expenditure estimation was based on the following parameters (as listed in Table 1). The quantity of water used for basic living activities was adopted from a report on domestic water consumption (ITRI, 2012). The price of bottled water was the average market price and the price of water from a water truck was asked during the group discussion. Respondents were asked to provide a water bill in order to estimate the expenditure on water during a normal day.

Table 1. Main parameters for averting expenditure estimations

Purpose	**The quantity of water used (daily per capita consumption)**	**Price**
Drinking water	Adult: 3.2 ℓ Child: 1.5 ℓ	Bottled water: 45 NT$/ℓ Friends/relatives: 0.01 NT$/ℓ (average water price in Tainan) Water truck: 0.4 NT$/ℓ Groundwater[2]: 0.002 NT$/ℓ
Personal washing & sanitation	Taking a shower: 32 ℓ Flushing the toilet: 34 ℓ	
Laundry	30 ℓ	
Other activities requiring tap water	38 ℓ	

Source: ITRI (2012), Grandjean (2005)

Participants were asked the following questions to elicit WTP for water supply stability and WTA compensation for a water outage day. A payment range from 0% to 100% was adopted for the WTP question, and an open-ended question was used for WTA compensation.

"Assume that the Taiwan Water Corporation provides a water supply priority program. If you pay more on the normal days, you will have a water supply priority during a water shortage and have water provided by truck to your house during a water outage. How many percent more, at most, of your water bill would you be willing to pay to join this program?"

"If our government had a program to make up for the inconvenience of water disruption, how much money would you accept as compensation for one water outage day?"

Since the water supply priority program has never existed in Taiwan or even been mentioned in the media, the WTP question had a very low response rate (19%) although we did prompt the current water price. Only the results of the WTA question will be used in the loss estimation.

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[1] In Taiwan, it is popular to eat outside or to take out food from a restaurant instead of preparing food at home. This is caused by the great variety of restaurant options, which offer a meal at a comparatively low price. Due to this fact, difficulties in estimating whether the outage changed eating habits and thus increased the loss or if this routine remained unchanged were encountered. Since a great majority of the interviewees inhabit residential buildings, it seemed to be justified to skip the amount of water needed to grow food.

[2] The calculation of groundwater usage cost was based on the average net water head, pumping power and efficiency. It assumed a daily operation of one hour and the lowest tariff for the electricity price in Taiwan. The estimation was performed by Dr. Chung-Feng Ding of the Tainan Hydraulics Laboratory, National Cheng Kung University, Taiwan.

2.2 Study area and survey

A rough map of the water outage areas after the Meinong Earthquake (February 6th, 2016) was provided by the Taiwan Water Corporation. To determine the exact locations of the water outage areas for the survey, we contacted community leaders in those areas and asked them to recruit residents who had experienced water outages to the focus group discussions. Three areas and 5 communities were surveyed. They were Huweiliao in the East District of Tainan which consisted of the Wensheng, Guansheng and Yusheng communities, Yuguangdao community in Anping District, and the Dalin community in the South District. One representative of each household could participate. In total, 46 residents participated in 4 focus group discussions and personal questionnaire survey during July 2017 and January 2018. Four cases, however, had to be further excluded from the estimation as they did not meet the set criteria (no outage experience or more than one person from the same household). In the first part, we held group discussions, where interviewees were asked about their experiences. This was done to recognize the various kinds of behavior during the water outage. The second part was paper-based and anonymous questionnaires. Each of those two parts took approximately one hour. The survey contained 22 questions that included demographic characteristics, regular water expenditure, water outage experiences, and contingent valuation.

3. RESULTS

Table 2 provides a summary of the daily averting expenditures at the household and per capita levels. Since the price of tap water is low in Taiwan, the water from temporary water stations was provided free, and most victims bought bottled water for drinking, the major differences in per household per day averting expenditures were based on whether victims brought water from a water station or went to their friends' and relatives' homes to take a shower and do their laundry, or used water sold commercially. The lower bound loss of water outage was calculated based on the averting expenditures less the expenditure on water during a normal day (Eq. 2). On average, households encountered daily losses of NT$271.09 a day, which accounted for 0.44% of monthly income.

Table 2. Daily averting expenditures and the lower bound loss estimation

	N	Mini.	Max.	Mean	S. D.
Per household averting expenditures [NT$]	42	20.80	776.00	280.59	204.44
Per capita averting expenditures [NT$]	42	4.20	408.00	75.78	75.90
Per household losses [NT$]	42	14.57	759.88	271.09	202.41
Per capita losses [NT$]	42	2.91	401.40	72.99	75.24
Daily loss to monthly income ratio [%]	33	.0021	1.52	.44	.39

Table 3 presents a summary of the upper bound losses. On average, a representative of a victim household as a result of the event would accept NT$736.95 for every water outage day for his/her family. To find the determinants of the water outage loss, a multi-variable regression is usually adopted. That was not possible due to the small sample size. The relationship between the number of household members and the stated WTA was investigated using the Pearson correlation coefficient, which showed a positive correlation between the two variables, $r = .34$, $n = 42$, $p < .03$, with more household members associated with higher values of WTA. As only one representative of each household could participate in the survey, the concern of this study was whether the stated WTA fully illustrated the inconvenience felt by the whole family, rather than the individuals. Daily per household losses had a mean of NT$1008.05, while per capita daily losses had a mean of NT$247.13, which amounted to 1.72% of monthly income.

Children and older adults (over 65 years old) are usually the most affected demographic groups in cases of emergency (Cutter et al., 2003). Therefore, the relationship between these two groups and the loss/income ratio was investigated using the Pearson correlation coefficient. There was a strong positive correlation between the number of children in a household and the lower bound loss to income ratio, $r = .74$, $n = 33$, $p < .001$, with a greater number of children associated with a higher loss to income ratio. This may have resulted from families with small children (below 6 years old) needing to spend more on alternative water sources, as they might be more concerned about the water quality. During the focus group discussions, some residents mentioned that public water trucks provided by the Tainan Fire Bureau were previously used to drain water from rivers and could not be cleaned.

Table 3. Summary of upper bound losses

	N	Mini.	Max.	Mean	S. D.
WTA	42	0	5000	736.95	916.73
Per household losses [NT$]	42	20.22	5308.08	1008.05	954.89
Per capita losses [NT$]	42	10.11	758.30	247.13	188.53
Daily loss to monthly income ratio [%]	33	.0758	15.17	1.72	2.70

In the case of the upper bound evaluation, there was a positive correlation between the number of elderly (over 65 years old) in a household and the loss to income ratio, $r = .49$, $n = 33$, $p < .001$. It was caused by the relatively low per capita income and the higher value for WTA compensation for the inconvenience caused. During the focus group discussions, many of the elderly referred to the difficulty in bringing in water from a temporary water station or public water truck. Only when people bought water from private water trucks, could they be provided with the service of having water pumped into their standpipes which could then supply water to their washing machines. Some victims even got injured when they tried to carry water to their homes. This situation shows that, in some cases, the lower bound estimation might not be sufficient and may lead to an underestimation of the real losses.

4. THE LOSS FROM THE GAOPING RIVER WEIR FAILURE AND THE BENEFIT OF DROUGHT MITIGATION

The loss from a water outage can be used in cost-benefit analysis, i.e., the benefit of drought mitigation. This idea was adopted by Fisher et al. (1995) more than 2 decades ago. However, many previous papers, regardless of the loss in the residential sector, and most water resource models have evaluated the amount and/or the probability of a water shortage rather than of a water outage. Since the shortage may be offset by reservoirs, water rationing and standpipes, the loss is incurred when a water outage really happens. Hence the drought levels and the capacity of the standpipe were studied in this paper.

4.1 Case study description

The Water Resource Agency of Taiwan has conducted a risk analysis of water resource supply and demand in the Kaohsiung area (NCKU, 2015) which simulated 12 scenarios involving water shortages including various levels of water supply facility failures with the current climate conditions as well as climate change. Using the predicted water supply and demand, this report estimated the number of water shortage days, the total amount of the shortage (measured in tons of water shortage), as well as the overall shortage ratio for every district in Kaohsiung City. Shortage, therefore, occurred if the demand in a district exceeded its supply. The predicted water supply and demand was based on the official water resource plan (EITCO, 2012) which already considers the dynamic water allocation, population growth, industrial development and current efforts to promote water conservation. The water shortage in the residential sector was simulated in the first two scenarios. Scenario one assumes a fully-functional Gaoping river weir, while scenario two assumes its partial (50%) failure. Both of these scenarios were predicted under the current climate conditions. These 2 scenarios were chosen because the Gaoping river weir is located near a fault, which matches the previously presented study in Tainan.

Kaohsiung City is a neighbor of Tainan City and has a very similar climate. According to statistics provided by the Taiwan Water Corporation (TWC, 2013), residents in Kaohsiung consume on average 268 liters of water per capita per day. Our study in Tainan revealed a similar amount of 279 liters of water per capita per day. Therefore, the loss from a water outage evaluated in this study can be applied to the Kaohsiung scenarios. If the per capita daily water consumption and the average water price are used to estimate the loss of water outage, it becomes only NT$2.79 per one water outage day which is obviously too low.

4.2 Estimation of benefits

Since the loss from the water outage was evaluated based on the per capita per day scale, the water shortage was estimated at the scale of district. In Taiwan, water rationing in order to mitigate a drought is based on a drought indicator that classifies the water scarcity into 5 stages. There are restrictions on outdoor water usage, such as fountains, and leisure usage, such as swimming pools, and water pressure reduction in off-peak hours in the first 2 stages. As for the third stage, there is a shortage rate of 10-30% and water becomes unavailable (Huang et al., 2012). Therefore, the average of the shortage (20%) from this stage was taken as a threshold value. We only estimate the loss for districts with shortages that exceeded 20%. The shortage per person per day was estimated according to the equation:

$$S_d = SD / DS / P \tag{5}$$

where SD denotes the annual amount of water shortage in a district; DS denotes the number of water shortage days; P is the population connected to the public water supply in the district. According to the building code in Taiwan, every residential building must have a water tank (standpipe) with the volume ensuring storage of water corresponding to 10% of daily water usage. Therefore, the water provided by the water tanks was calculated as follows:

$$WT = 0.1 \cdot C \tag{6}$$

where C is the average water consumption per day. If the daily water shortage is greater than the amount that the water tank can cover (S_d >WT), then it is assumed that an outage occurs. Then, the per capita (per day) loss of water outage, the population and the water shortage days were used to estimate the annual total loss for the residential sector. In scenario I only one district is affected by the water outage. Therefore, the annual benefits from avoidance are estimated to be 0.06 billion and 0.20 billion Taiwanese dollars for the lower and upper bound, respectively. In scenario II, 29 out of 38 districts might experience a water outage. The benefits from avoidance could reach 31.62 billion and 107.05 billion Taiwanese dollars for the lower and upper bound estimations, respectively. Therefore, with regard to the residential sector, if the cost of reinforcing the Gaoping river weir exceeds NT$31.62 billion, it is definitely not worth to do. If other mitigation measures, such as building extra water storage facilities in a district or community, are to be considered, this method can be used in the cost-benefit analysis as well.

5. CONCLUSION

This study has estimated the losses due to a water outage in the residential sector. It has combined two methods that are commonly used in assessments related to an interrupted water supply: the averting expenditure and contingent valuation methods. The averting expenditures excluding the expenditure on water on a normal day represent the lower bound of the estimation.

The main limitation of averting expenditures includes the lack of an estimation of the inconvenience and/or loss in terms of health. This study, therefore, has applied the WTA method to measure the level of inconvenience. The lower bound plus the willingness-to-accept compensation for the inconvenience is regarded as the upper bound estimation. People who really experienced a long period of water outage were surveyed. The result of the upper bound estimation showed that inconvenience had a high value, increasing daily per capita losses from NT$72.99 (lower bound) to NT$247.13 (upper bound). The results, moreover, showed a positive correlation between the loss to income ratio and the number of elderly people in the household. According to the focus group discussion, elderly people experienced the greatest difficulty in gathering water from alternative sources. This fact shows that the inconvenience resulting during an emergency situation is high and should not be omitted in loss estimations. The results based on the averting expenditure (lower bound estimation) show that households with children (below six years old) could be another group that is vulnerable in the event of a water outage.

The application of the loss in the event of a 50% Gaoping River weir failure illustrated how the results of this study could be used in the cost-benefit analysis of water shortage mitigations. A threshold for the water shortage that may start to occur as a result of the water outage and the capacity of residential water storage facilities, such as the standpipe, were determined. The annual loss resulting from a 50% Gaoping River weir failure in the residential sector could reach NT$31.62 billion and NT$107.05 billion at the lower and upper bound estimations, respectively.

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