Households' preferences to avoid disturbances in municipal drinking water supply: A nationwide contingent valuation study in Sweden

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Contingent valuation is applied to study Swedish households' preferences to avoid experiencing adverse consequences caused by outages and restrictions in the municipal drinking water supply. The frequency of such drinking water supply disturbances is increasing globally due to, e.g., climate change and deteriorating water supply infrastructure. We estimate the willingness to pay (WTP) for investments that would help avoid a one-time occurrence of three situations: (A) a total outage of tap water delivery; (B) tap water must be boiled to be fit for drinking; and (C) restrictions against particular uses of tap water. Three different duration times per situation are considered. Mean WTP estimates are robust to the estimation method choice – parametric or non-parametric – but show scope insensitivity for the longest duration times of situations A and B, and all duration times of situation C. Household income has an expected positive and significant effect on WTP for all situations, and a test of budget sequence sensitivity does not indicate overestimation of adding up WTP estimates for two or three situations. Implications for decision-makers are discussed, including efficiency and equity trade-offs, and the use of the WTP estimates in cost-benefit analyses of investments in preventive measures.

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1 Introduction

Access to sufficient and safe drinking water is of key importance to society and recognized by the United Nations (UN, 2010) as a human right. Unsafe water quality or supply disruptions can cause severe consequences ranging from health effects (WHO, 2022) to negative effects on water-dependent businesses (e.g., Sjöstrand et al., 2021). The Swedish Water Services Act (SFS, 2006) defines the supply of drinking water for residential use as the primary task of public water providers, which, in the case of Sweden, are the municipal water utilities. Their drinking water supply systems are typically based on surface water sources, such as lakes and rivers, or groundwater sources (i.e., aquifers), and distribute to about 90 percent of Swedish households. The households pay for this, and sewage-related, services through their water and sewerage bill. The total of the bill depends on a water and sewerage rate decided by the municipality and based on a cost-recovery principle. Consequently, it is crucial for Swedish society that the water utilities are able to ensure reliable and safe drinking water supply.

The World Health Organization (WHO) recommends the development of Water Safety Plans to identify hazards, estimate risk levels, and define control measures as part of the overall drinking water management, where risk levels refer to the product of the probability of a hazardous event and its consequences (WHO, 2023). This approach is also part of the EU Drinking Water Directive (2020/2184). In Sweden, the water supply is generally well-functioning, but the importance of a proactive and risk-based approach has been highlighted during the last two decades by undesired and costly events, such as waterborne disease outbreaks and droughts (MSB, 2014; Sjökvist et al., 2019). Many supply systems, in Sweden and other countries, are also exposed to new and increasing threats due to climate change, deteriorating supply infrastructure, population growth, urbanization, and other factors (Sjöstrand, 2020).

However, undertaking risk-reducing measures involves costs, which creates the need for a basis to enable well-informed prioritizations among different potential measures to maximize the net benefits of risk-reducing investments. This paper contributes to improving our understanding of the benefit side by analyzing households' preferences with respect to avoiding the consequences of undesired events related to the supply of drinking water. Examples of undesired events include droughts affecting the drinking water production capacity of the water source, chemical and microbial contamination of the water source, technical failures in treatment plants, and pipe breaks and other failures in the infrastructure of the distribution system. The chain of undesired events may look different, but from the perspective of a consumer of drinking water, three key situations can be identified: (A) a total outage of tap water delivery; (B) tap water is delivered but it has to be boiled to be fit for drinking; and (C) tap water is delivered but there is a need to reduce the total water consumption and therefore restrictions are imposed against particular uses of tap water.

Measures to improve the security of the drinking water supply can be extensive and require large investments. The Swedish Water and Wastewater Association (SWWA, 2023a) concludes that Swedish municipalities must increase the investment in drinking water and wastewater infrastructure from their current level of SEK 21 billion to SEK 31 billion per year in order to meet future challenges and demands. Therefore, data demonstrating the benefits of improvement measures to drinking water consumers is of key importance to support decision-makers. The type and magnitude of investments might vary by municipality due to differing conditions with respect to, e.g., land area and the current technical status of the supply system. Furthermore, the fact that decisions about investments are made at the municipal level suggests that benefit estimates should also be municipal-specific. However, the level of benefits might vary depending on local socio-economic conditions (such as the average income of residents), which indicates that equity aspects need to be considered when using the outcome of municipal-specific cost-benefit analysis (CBA) as a basis for decisions.

Estimates of the willingness to pay (WTP) to avoid *consequences* associated with situations such as A, B, and C can subsequently be combined with probabilities to feed into CBAs of risk-reducing investments. Surprisingly, previous meta studies focusing on the economic valuation of drinking water services have found that the benefits associated with the delivery of drinking water to households and other provisioning services, are, in general, less studied in comparison to other services provided by water bodies (Brouwer et al., 2009; Reynaud and Lanzanova, 2017). Such shortcomings could prohibit performing accurate CBAs of water protection measures, an issue already raised in a US context by Keiser et al. (2019) and Keiser and Shapiro (2019).

While there is information on the financial consequences that businesses in Sweden suffer due to short and long-term water delivery disruptions (Sjöstrand et al., 2021), there are no corresponding studies for Swedish households. Existing valuation estimates suitable for benefit transfer are also lacking (Wahtra et al., 2021). The literature analyzing households' WTP to avoid situations similar to A, B, and C includes: Hensher et al. (2005), Genius et al. (2008), Hatton MacDonald et al. (2010), Latinopoulos (2014), and Tanellari et al. (2015) for situation A; Appiah et al. (2019) and Liu and Klaiber (2023) for situation B; and Griffin and Mjelde (2000) and Turpie and Letley (2023) for situation C. However, the WTP estimates from these studies are not considered transferable to a Swedish setting for evaluating measures to improve drinking water security with respect to situations A, B and C. This is because the earlier studies are often case-study specific and differ with respect to the design of the valuation and policy scenarios, and the study site conditions in terms of, e.g., climate, hydrology, and cultural factors. This suggests a need for new primary valuation studies – such as the one presented in this paper. The results could support decision-making regarding investments in risk-reducing measures in Swedish settings but, importantly, through benefit transfer, also in international ones. In Sweden and many other countries, there is no functioning market for tap water (De Paoli et al., 2016). This calls for the use of non-market valuation methods such as contingent valuation, which we apply to obtain estimates relevant to policy appraisal concerning the benefits of risk reduction measures preventing undesired events in the delivery of municipal drinking water. Specifically, the objectives of the study are: (i) estimate Swedish households' WTP to avoid the consequences of each of the three key situations A, B, and C; (ii) investigate to what extent household characteristics such as income and attitudes influence WTP and what this implies in terms of variations in municipal-specific benefits; and (iii) evaluate the implications of using WTP estimates in light of two methodological issues: scope sensitivity with respect to the duration times of the three situations, and budget sequence sensitivity, which could indicate overestimation of adding up WTP estimates for the situations.

2 Methods and materials

2.1 Theoretical framework

Following Kriström and Johansson (2021), the consequences for a household's wellbeing from experiencing the three situations, indexed i = A, B, and C, are captured by the household's indirect utility function $V(\cdot)$:

$$v = V(t_i, y, g_i), \tag{1}$$

where v is utility, t_i is the duration of a particular situation, y is disposable income, and g_i is a vector of the non-priced aspects associated with not experiencing the situation, e.g., the value of having convenient access to drinking water, where v is expected to be increasing in y and g_i but decreasing in t_i. Prices of market goods are assumed to be constant and are thus suppressed in Equation (1).

Assuming mutually independent situations and each situation occurring either once (superscript 1) or never (superscript 0), a household's WTP to avoid having one of the situations, say A, occur once during a specific amount of time is defined as the equivalent variation (EV_A) (Freeman III et al., 2014):

$$V(t_A^1, y^1, g_A^1) = V(t_A^0, y^0 + EV_A, g_A^0), \tag{2}$$

where $EV_A < 0$ and $t_A^0 = 0$. t_i and g_i for B and C are constant and therefore suppressed in Equation (2). The WTP to avoid one occurrence of B and C, respectively, can be defined analogously to EV_A in Equation (2) as EV_B and EV_C.

To estimate EV, one option is to use avoided household expenditures. For example, EV_A could be approximated from data such as the cost of bottled water, fuel costs for driving to a location where emergency water is supplied, lost working hours, etc. However, the avoidance of such financial losses is likely to underestimate EV_A because non-priced aspects (g_i), such as reduced convenience, are not captured. This suggests the use of stated preference methods, such as contingent valuation, because of their ability to pose direct questions about WTP for avoiding the situations and thereby allowing estimation of the full value of EV.

Some risk-reducing measures may affect more than one of the situations, which makes it important to assess whether separately estimated equivalent variations are additive or not. In general, this depends on whether due consideration has been given to the impact on the household's budget constraint. Ignoring situation C for the sake of simplicity, the household's WTP to avoid one occurrence of situation A *and* one occurrence of situation B is defined as EV_{AB}:

$$V(t_A^1, t_B^1, y^1, g_A^1, g_B^1) = V(t_A^0, t_B^0, y^0 + EV_{AB}, g_A^0, g_B^0),$$

where $EV_{AB} < 0$. A theoretically equivalent way of arriving at EV_{AB} is to follow a sequential approach with respect to the impact on the budget restriction (Freeman III et al., 2014). Starting the sequence with situation A implies that:

$$\begin{aligned} V(t_A^1, t_B^1, y^1, g_A^1, g_B^1) &= \\ V(t_A^0, t_B^1, y^0 + EV_A, g_A^0, g_B^1) &= \\ V(t_A^0, t_B^0, y^0 + EV_A + \widehat{EV_B}, g_A^0, g_B^0), & \end{aligned} \tag{3}$$

where, in absolute values, $EV_A + \widehat{EV_B} = EV_{AB} < EV_A + EV_B$. However, whether a sequential or non-sequential approach to the budget restriction results in significantly different estimates in a specific application is an empirical issue, and such budget sequence sensitivity is tested in this study.

2.2 Data collection

A stated preferences method application involves many theoretical and empirical path choices (Johnston et al., 2017), which were gradually resolved in this study through the process of developing a survey instrument including valuation scenarios. This process included: (i) input from a reference group mainly consisting of representatives of municipal water utilities; (ii) focus group testing in October 2021 with participants from the general public who have municipal drinking water; and (iii) a pilot study in January 2022 with 221 panelists in a national web panel (see below), including follow-up telephone interviews with eleven panelists. The focus group testing mainly targeted participants' understanding of the contents in draft information texts about municipal drinking water and situations A, B, and C, as well as participants' views on paying to avoid the situations and the associated payment vehicle.

The pretesting strongly indicated that the cognitive burden associated with the valuation task should be reduced as much as possible. At the same time, there was no indication that the situations had to be defined in terms of individual attributes other than duration times. In the further development of the survey instrument, we therefore selected a contingent valuation setup in which WTP for each type of situation is elicited separately, i.e., EV_A, EV_B and EV_C are estimated one by one, and the number of duration times for each situation is limited to three. This resulted in nine different versions of the questionnaire (1–9), which were supplemented by two versions (10–11) for testing budget sequence sensitivity (see Table 1 for an overview). The complexity of the valuation task was also reduced by making the valuation scenarios consider a one-time payment per household for avoiding only one occurrence of each situation. However, the questionnaire included a close-ended follow-up question on how much more the household would be willing to pay to avoid a second occurrence.

In the pilot study, the households' typical way of paying their water and sewerage bill was successfully tested as the payment vehicle. Moreover, the WTP of each household was elicited through an interval open-ended question (Håkansson, 2008), which provided a basis for designing a payment card (PC) that was used in versions 1–9 in the main study, see Supplementary Material SM1.1 for details on the application of this commonly used WTP elicitation format (Czajkowski et al., 2024).

Table 1: Overview of questionnaire versions

Questionnaire version	Situation (type of undesired event)	Duration time	WTP elicitation
1	A	24 hours	Payment card
2	A	1 week	
3	A	1 month	
4	B	24 hours	
5	B	1 week	
6	B	1 month	
7	C	1 month during the summer half-year	
8	C	3 months during the summer half-year	
9	C	6 months during the summer half-year	
10	A, B, and C	A: 1 month, B: 1 month, C: 6 months during the summer half-year	Interval WTP question. Sequential design with respect to budget restriction
11	A, B, and C	A: 1 month, B: 1 month, C: 6 months during the summer half-year	Interval WTP question. Non-sequential design with respect to budget restriction

Note: Situations refer to: (A) total outage, (B) water must be boiled, and (C) restrictions in use. See Section 1.

The separate estimation of EV_A, EV_B, and EV_C necessitates further analysis to determine whether the estimates are additive; otherwise, they could not be used to evaluate the benefits of measures targeting more than one type of situation. This was done by questionnaire versions 10 and 11 in which respondents met scenarios for all three situations, but the budget restriction was formulated sequentially in version 10 and non-sequentially in version 11 (Q22b, Q23b, Q22c and Q23c in SM2). The interval open-ended WTP question used in the pilot study was kept in versions 10 and 11, which enabled a comparison to PC WTP results. The full questionnaire, including the valuation scenarios and WTP questions used in the main study, is available in SM2.

In the pilot study and the main study, the questionnaire was administered through the survey company Norstat to its web panel, which is recruited with the aim of being representative of the Swedish population. Self-recruitment is not allowed. When panelists are invited to answer a questionnaire, they are only informed about the estimated time required for completion and their remuneration for providing a complete answer. The panelists are thus not aware of the topic of the questionnaire before they accept the invitation, which avoids selection bias at this stage in terms of over-representation of panelists interested in the survey topic. The main study, targeting panelists living in households with municipal drinking water supply, was carried out from 17 May to 5 June 2022. Out of all panelists invited to answer the questionnaire, about 35 percent accepted, but 26 percent of those who accepted did not qualify as respondents due to the following reasons: household having private (not municipal) drinking water (12%), and questionnaire only partially completed (6%) or not completed before the survey company closed it (8%). Norstat judged these results to be as expected for a questionnaire of this type.

The questionnaire versions were randomly assigned to the panelists until at least 200 responses per version were gathered, resulting in eleven subsamples. To check the representativeness of the survey data, we compared mean values for the covariates in all versions – disaggregated and aggregated – to national data found in official reporting.[1] Overall representativeness was high, but average income (TINC) and share of individuals with higher education (EDU) was larger in the survey data compared to the Swedish average, which is common in these types of studies (e.g., SAHCSA, 2021; SCCA, 2021; UoG, 2024). The complete comparison is reported in SM1.6.

While exclusion of respondents based on arbitrary response latency thresholds should be avoided (Campbell et al., 2017), the research team tested what time is needed as a minimum to read through the information texts and questions; we assessed that 11 respondents with a response latency shorter than 3 minutes must have skipped some text sections and should therefore be excluded. The mean response latency for the remaining 2199 respondents (Table 2) was 18 minutes (median: 12 minutes). As regards respondents protesting against the valuation scenario, protest answers were identified through a close-ended debriefing question posed to respondents reporting zero WTP, see Table 2 and SM1.2 for details.

2.3 Econometric approach

We estimated the expected value of WTP non-parametrically by using the maximum likelihood (ML) Turnbull estimator (Turnbull, 1976). The lower and upper bounds of E[WTP] were calculated following Haab and McConnell (2002), the former by multiplying each PC value by the probability that the WTP lies between that value and the next highest one, providing a conservative estimate of E[WTP] for all non-negative distributions independently of the true underlying distribution of WTP responses. The procedure for calculating the upper bound of E[WTP] requires defining the bid above the highest PC value. This bid was assumed to be SEK 10,001, since no respondent used the open-ended

[1] National data was retrieved from the governmental agency Statistics Sweden.

Table 2: Respondents to each questionnaire version and respondents giving a zero WTP answer, some of whom were identified as protesters (see SM1.2 for details)

Version and situation studied	Total number of answers	% zero WTP answers	% protest answers of all answers
1 A 24 hours	202	34.7	4.0
2 A 1 week	199	28.1	1.0
3 A 1 month	201	25.4	4.5
4 B 24 hours	199	37.7	4.0
5 B 1 week	203	26.6	2.5
6 B 1 month	197	27.9	4.6
7 C 1 month	197	36.0	7.1
8 C 3 months	199	26.6	2.0
9 C 6 months	200	26.0	5.0
10 A 1 month	201	22.4	2.0
10 B 1 month		28.9	5.0
10 C 6 months		41.3	5.0
11 A 1 month	201	23.9	4.0
11 B 1 month		30.8	5.5
11 C 6 months		39.3	8.0
Sum	2199	30.3	4.2
1–9	1797	29.9	3.8

option of stating a WTP above SEK 10,000.[2]

We also followed a parametric approach for estimating the expected value of WTP and for explaining the variation in WTP responses. A key feature advising the choice of econometric model is the observed pattern of WTP responses (Johnston et al., 2017), which in our case was a highly skewed distribution due to a substantial number of zeros; about 30 percent for questionnaire versions 1–9 (Figure SM1.3.1). Czajkowski et al. (2024) note a general lack of guidance concerning parametric modeling of contingent valuation data and advocate a flexible model choice approach by testing different model specifications. They show the benefits of this approach by applying several different specifications on skewed data obtained through a PC elicitation format, and we use three of those: a negative binomial regression model; an interval regression model; and a zero-inflated negative binomial regression model (see SM1.3 for details). For the regressions, the data collected through the nine questionnaire versions were aggregated for situations A, B, and C by merging the subsamples for versions 1–3, 4–6 and 7–9, respectively. To study the impact on WTP from an increased duration time for each situation (Table 1), two dummy variables were introduced: MEDTIME (= 1 for respondents to versions 2, 5 and 7) and LONGTIME (= 1 for respondents to versions 3, 6 and 9). All regressions were performed in STATA, version 17, using robust standard errors.

[2] In this paper, monetary amounts are mostly expressed in Swedish krona (SEK) to keep the link to the amounts stated in the PC. The average ECB exchange reference rate in the first half of 2022 was EUR 1 = SEK 10.48.

3 Results

3.1 Survey outcome

Out of the 1797 completed questionnaires for versions 1–9, 359 (20%) respondents stated that they would be willing to pay something to avoid the situation, 926 (51.5%) stated that they maybe would be willing to pay, and 512 (28.5%) stated that they would not be willing to pay anything. When the 1285 respondents who indicated that they would, or maybe would, be willing to pay something were asked *how much* they would be willing to pay, 182 of them answered "I don't know" (i.e., 10.1% of 1797, the total number of completed questionnaires), and another 25 stated a zero WTP, making the total number of zero responses 537 (512+25, i.e., 29.9% of 1797) and the total number of respondents with a positive WTP 1078 (1285−182−25, i.e., 60.0% of 1797). Sorting out protest answers (see Section 2.2 and SM1.2) gave 468 true zero answers. Regarding reasons for having a positive WTP (Q25), the two most frequent ones were "I want a secure water supply for my household and other households" (55%), and "the situation would cause inconvenience to my household" (26%).

Table 3 presents descriptive statistics of WTP responses for the nine different questionnaire versions, excluding protest and "I don't know" answers.[3] The number of zero responses is between 24 and 38 percent. For situations B and C, mean WTP point estimates increase consistently for a longer duration time of the situation, and for situation B the estimates for 1 week and 1 month are significantly greater than those for 24 hours according to 95 percent confidence intervals. For situation A, mean WTP for 1 month is slightly lower than that for 1 week, though not significantly. Naturally, the Turnbull estimates follow the same pattern, but concerning median WTP we only observe consistent increases for situation A as the duration time rises. Sensitivity of scope with respect to duration time is further studied in Section 3.4.

The numbers reported in Table 3 concern WTP to avoid one occurrence of each of the three situations. We obtained indications about the households' WTP to avoid an additional occurrence through a follow-up question (Q26) to the respondents who had a positive WTP to avoid one occurrence. For all three situations, the WTP to avoid an additional occurrence turned out to be, on average, about 70 percent of the WTP for the first occurrence (see SM1.7 for details). The mean WTP estimates in Table 3 suggest that households are willing to pay around 100–300 percent of their average monthly water and sewerage bill; this average amounts to SEK 768 for households residing in detached houses and SEK 477 for those living in apartments (SWWA, 2023b). Excluding respondents who found the information texts difficult or very difficult to understand (Q35), the questions difficult or very difficult to answer (Q36), and those who were most uncertain about their WTP response (Q24), has only minor effects on mean WTP. The same holds when excluding possibly "inconsistent" respondents, i.e., those who initially indicated that they would, or maybe would, be willing to pay, but then stated zero WTP. See SM1.4 for details about these sensitivity tests.

[3] Summary statistics for WTP responses above zero are presented in SM1.3.

Table 3: Summary statistics of one-time household WTP responses (SEK) for questionnaire versions 1–9, excluding protest votes and “I don’t know” answers

Version	Turnbull lower bound	Turnbull upper bound	Mean [95% c.i.]	SD	Median	*n*	WTP = 0 (%)
1 A 24 h	841	1096	982 [686, 1277]	1970	220	173	36%
2 A 1 week	1048	1423	1282 [949, 1615]	2233	300	175	31%
3 A 1 month	1034	1403	1249 [968, 1530]	1896	545	177	24%
4 B 24 h	572	776	689 [474, 905]	1445	150	175	38%
5 B 1 week	1065	1366	1216 [919, 1513]	1986	545	174	28%
6 B 1 month	1153	1462	1308 [981, 1634]	2170	400	172	27%
7 C 1 month	964	1244	1104 [793, 1415]	2025	300	165	35%
8 C 3 months	994	1285	1140 [826, 1453]	2028	545	163	30%
9 C 6 months	1074	1376	1225 [919, 1531]	2034	545	172	24%

Notes: Arithmetic mean, standard deviation (SD), and median are based on PC interval midpoints. Turnbull estimations (lower and upper bound) are calculated from the PC values (see Section 2.3).

3.2 Regression results

Data on variables potentially explaining the variation in respondents’ WTP were obtained through the survey. The variables included basic household facts, also obtainable at an aggregate level from official statistical databases in Sweden. These were, e.g., gender, age, income, and the number of household members, but also survey-specific information about the households’ knowledge, experience, and attitudes related to drinking water. The list of variables also included a geographical dummy variable for respondents residing in the counties of Blekinge, Kalmar and Gotland in the southeastern-most part of Sweden. These counties have previously been particularly affected by water usage restrictions because of summer drought episodes, which might make inhabitants more reluctant to experience similar situations again. All covariates used in the regression models are presented with descriptions and summary statistics in SM1.4.

The results from the regression analysis, using the specified negative binomial regression model for situations A, B, and C, respectively, and the estimated mean WTPs for all nine questionnaire versions are also found in SM1.4. The results suggest a relatively weak overall explanatory power with few covariates having coefficients significantly different from zero. Two important exceptions are the significant impact of household income and the duration times of the situations, see SM1.4 for details. Note also from SM1.4 that the model results concerning mean WTP estimates and associated confidence intervals are very similar to those reported for arithmetic mean WTP in Table 3. As to the sensitivity of results to model choice, SM1.5 reports the estimation results for the two alternative models, i.e., interval regression and the zero-inflated negative binomial model. The comparison between the three models in SM1.5 suggests that the differences between the models with respect to performance are minor, and the key results are robust to model choice.

3.3 Models tailored to data available from official statistics

The full models, whose results are reported in SM1.4 and SM1.5, and summarized in Section 3.2, are partly based on variables for which data can only be obtained through household questionnaires. Undertaking such questionnaire studies is often beyond the scope of policy-making processes in individual municipalities. This suggests a need for models that are tailored to local conditions where the only available data source is official statistics. Estimation results for such tailored models – again, using negative binomial regressions – are presented in SM1.6 and are overall similar to those of the full models.

Income has a positive and significant impact on WTP for all situations in the tailored models. To illustrate what this could imply if the tailored models were applied to real-world conditions in Swedish municipalities, we identified the municipalities with the lowest and highest mean disposable household income in 2021: SEK 30,700 and 157,000 per month (rounded to the nearest hundred). We also included the municipality with a mean monthly household income closest to the mean of all municipalities: SEK 41,600. Applying mean values for the other independent variables for these three municipalities resulted in the estimated WTPs reported in Table 4.[4] The last three rows of Table 4 show estimated WTPs for national averages for the overall Swedish population based on statistics reported in Table SM1.6.2.

The estimates from the tailored models should be interpreted as the estimated WTP of an average household in the respective municipalities, or for a nationally average household in Sweden. The results suggest a rather substantial sensitivity of WTP to income. For example, the WTP for avoiding 1 month of situation B is 3.7 times higher (2527/688) for the average household in the highest-income municipality than in the lowest-income one. This indicates that different municipalities should use different WTP estimates as a basis for computing benefits in municipal-specific CBAs of implementing measures that could help avoid the three situations. Even so, such a procedure could be questioned from an equity point of view (see the discussion in Section 4.2).

3.4 Scope and budget sequence sensitivity

Table 3 suggests that sensitivity may be present for certain scope levels and situations. We conduct four statistical tests to check for scope sensitivity (at the five percent significance level) with respect to the duration time of the three situations: two parametric tests and two non-parametric tests. Given the non-normal distribution of our data, the non-parametric tests were considered most appropriate (see, e.g., Yasunaga et al., 2006),

[4]Note that a preferred procedure to estimate WTP would be to use covariate values for all individuals residing in the respective municipalities, but such disaggregated data does not exist.

Table 4: Estimated one-time WTP (SEK) for an average household in three municipalities, characterized by having the lowest, the mean and the highest disposable household incomes among all Swedish municipalities, and in Sweden (national level)

Municipality and duration of the situation	Situation A	Situation B	Situation C
Highest-income, A and B: 24 h; C: 1 month	2045	1319	1757
Highest-income, A and B: 1 week; C: 3 months	2928	2430	1641
Highest-income, A and B: 1 month; C: 6 months	3068	2527	2005
Middle-income, A and B: 24 h; C: 1 month	904	498	1232
Middle-income, A and B: 1 week; C: 3 months	1295	917	1151
Middle-income, A and B: 1 month; C: 6 months	1357	953	1406
Lowest-income, A and B: 24 h; C: 1 month	860	359	1068
Lowest-income, A and B: 1 week; C: 3 months	1231	661	998
Lowest-income, A and B: 1 month; C: 6 months	1290	688	1219
National level, A and B: 24 h; C: 1 month	937	566	1239
National level, A and B: 1 week; C: 3 months	1342	1042	1158
National level, A and B: 1 month; C: 6 months	1407	1084	1414

Notes: Results are based on the regression coefficients and covariates presented in Table SM1.6.1. The last three rows (10–12) report estimated WTP based on the regression coefficients in Table SM1.6.1 and national averages of all covariates as reported in Table SM1.6.2. Results are presented for all duration times for all three situations.

while the parametric ones served as robustness checks (with results presented in SM1.8). Importantly, the results are largely consistent with each other across all tests.

For the non-parametric tests, we apply first the Kruskal-Wallis test, see, e.g., Memon and Matsuoka (2002) for its previous use in contingent valuation contexts. It examines whether the distributions of WTP differ across scope levels (based on ranks, not means). We then carry out pairwise comparisons between scope levels using Dunn's test, adjusting for multiple comparisons (i.e., controlling for Type I error).

First, we conduct the scope sensitivity tests at the situation level, grouping respondents in versions 1–3 under situation A, versions 4–6 under situation B, and versions 7–9 under situation C (see SM1.8 for details). Second – motivated by the significance of income in the regression analyses in Sections 3.2 and 3.3 – we analyze each of the three datasets separately, to reveal whether scope sensitivity depends on income level. In particular, we categorize respondents into three income clusters (see Table 5) using the k-means approach whereby the data is partitioned into a predefined number of clusters by minimizing the variance within each cluster and maximizing the variance between clusters (MacQueen, 1967). We then perform the scope tests again for each income cluster and situation.

Beginning with situation A (versions 1–3), the Kruskal-Wallis results suggest that scope sensitivity exists ($p = 0.0163$), and Dunn's post-hoc test confirms that WTP is significantly higher for the 1-month scope compared to the 24-hour scope ($p = 0.0018$). When dividing the respondents in situation A into income clusters and re-running the tests for each cluster, the Kruskal-Wallis test did not reveal any significant differences in mean WTP across the scope levels (p-values for clusters 1A and 2A are only significant at a 10 percent significance level, $p = 0.0968$ and 0.0664). On the other hand, Dunn's pairwise comparison

Table 5: Income clusters for respondents to questionnaire versions 1–9, constructed using the k-means approach

Cluster ID	Questionnaire version	*n*	Percentile (cumulative)	Mean income (SEK)	Mean WTP (SEK)
1A	1–3	156	29.71	20 554	803
2A	1–3	306	88	49 092	1248
3A	1–3	63	100	125 993	1715
1B	4–6	323	62	31 043	801
2B	4–6	174	95.39	69 921	1341
3B	4–6	24	100	191 667	2717
1C	7–9	230	46	25 072	815
2C	7–9	246	95.2	62 926	1485
3C	7–9	24	100	196 875	1077

does find a significant difference in WTP between the 1-month scope and the 24-hour scope for clusters 1A and 2A (p = 0.0140 and 0.0098).

Turning to situation B (versions 4–6), the Kruskal-Wallis results indicate a significant difference in mean WTP across scope levels (24 hours, 1 week, and 1 month), with a p-value of 0.0005. This suggests that mean WTP varies by scope, warranting further post-hoc analysis to identify specific differences. Dunn's test shows significant differences in mean WTP between the 24-hour and 1-week scope, and the 24-hour and 1-month scope, with both p-values equal to 0.0003. When scrutinizing scope sensitivity depending on income levels, the Kruskal-Wallis test reveals significant differences in mean WTP across scope levels for respondents in income cluster 1B (p = 0.0017). Dunn's post-hoc test suggests significant differences between the 1-week and 24-hour scope (p = 0.0004), and the 1-month and 24-hour scopes (p = 0.0016), indicating that WTP is increasing with scope within this income cluster.[5] Moreover, Dunn's pairwise comparison reveals that WTP for the 24-hour scope is significantly lower than for the 1-month scope (p = 0.0320) for cluster 2B. Cluster 3B does not show any significant sensitivity to scope in any of the tests.

The final dataset includes respondents facing situation C (versions 7–9), for which we find no significant scope sensitivity, either for the dataset as a whole or across the separate income clusters. These results suggest that the scope levels in situation C (1 month, 3 months, or 6 months) do not significantly influence WTP.

In summary, our scope sensitivity tests indicate that scope sensitivity may be present in the lowest and middle-income clusters for situations A and B, but not in the highest income clusters. Where scope sensitivity is present, it is always between the 24-hour scope and either the 1-week or the 1-month scopes, but never between the 1-week and 1-month scopes.

Turning to budget sequence sensitivity, recall that questionnaire versions 10 and 11 included a sequence of WTP questions where a WTP question was first posed for situation A (1 month), and then for situation B (1 month) and C (6 months), respectively.[6] The

[5] Since the 1-week, and the 1-month, respondents have higher rank sums than the 24-hour respondents do.

[6] Recall that versions 10 and 11 used an interval open-ended WTP question whereas a payment card was used in versions 1–9. This provided an opportunity to test the potential impact of elicitation question format

formulation of the budget restriction was equal for situation A, but differed for the second and third WTP question: a sequential budget restriction was applied in version 10 and a non-sequential one in version 11 (Q22b, Q23b, Q22c and Q23c in SM2). The theoretical prediction at the end of Section 2.1 suggests that the former should result in a lower WTP than the latter. However, a number of statistical tests reported in SM1.9 indicate no significant difference in WTP between the sequential and the non-sequential treatment, possibly with the exception of high-income respondents. The empirical implication of this finding is discussed in Section 4.1.

4 Discussion

4.1 Scope and budget sequence sensitivity

While the overall explanatory power of the tested regression models is low, the results are robust regarding the size of mean WTP and the sensitivity of WTP with respect to household income. In addition, parametric and non-parametric mean WTP results are similar for situations A and B, and indicate a lower WTP to avoid a short duration time (24 hours) than to avoid duration times of 1 week and 1 month. The scope sensitivity tests in Section 3.4 confirm this finding and provide additional insights into the impact of income: significant sensitivity to increasing the 24-hour scope was found in the low and middle-income clusters, but not in the high-income cluster. Explanations for these results deserve further research, which should take into account the potential impact of one-time payments – see further discussions below on payment frequency. The results concerning scope sensitivity are quite strong given that a subsample approach was used (i.e., respondents in versions 1–9 were only treated with one situation and one duration time), with a modest number of respondents per subsample (~170). However, the mean WTP for the longer duration times of 1 week and 1 month remained approximately the same, with no significant scope sensitivity detected between these levels. For situation C, there is no significant difference in the mean WTP among any of the studied duration times of 1 month, 3 months and 6 months, and no significant scope sensitivity was found either for the dataset as a whole or for specific income groups.

Insensitivity of stated WTP to the duration of water supply shortfalls has been observed before (Brozović et al., 2007) and is a common issue in the contingent valuation literature (Ojea and Loureiro, 2011). Although widely studied, the underlying causes of scope insensitivity remain poorly understood, and the explanations could be many. In our case, the scope insensitivity to duration times of situation C – restrictions against particular uses of tap water – could potentially be interpreted as households perceiving no additional difficulties when the duration extends from 1 month to 3 or 6 months, perhaps because they do not find the situation particularly troublesome to begin with. However, for situations A and B, it seems unreasonable to assume that experiencing a total tap water outage or having to boil tap water for drinking for 1 month instead of 1 week would be equally burdensome. A more likely explanation could be a hypothetical bias, i.e., that respondents were unable to fully grasp the severity of extending the duration from 1 week to 1 month.

on WTP. The results in SM1.10 indicate no differences between the two formats with respect to mean WTP.

We therefore recommend that the WTP estimates for 1 month concerning situations A and B should be used with great care.

Another aspect related to scope is to what extent WTP is sensitive to the number of occurrences of the situations. Recall that the valuation scenario was delimited to the avoidance of one occurrence of each of the three situations. At the same time, preventive measures by water utilities might reduce the risk of multiple occurrences of a situation. It could thus be important to know households' WTP to avoid the same situation more than once. Indications about this WTP were obtained from the answers to the follow-up question Q26 about how much more a household would be willing to pay to avoid a second occurrence. The results indicate that the additional WTP was on average about 70 percent of the WTP to avoid the first occurrence, see SM1.7 for details. The 30 percent decrease in WTP might reflect a view among respondents that investments in measures to avoid a disturbance would contribute to avoiding more than one occurrence and thus make a second occurrence less likely. Also Hatton MacDonald et al. (2005, 2010) found a WTP significantly different from zero to avoid a second occurrence of water supply interruptions. It can also be hypothesized that the marginal disutility of experiencing an additional occurrence is decreasing ("we are used to handling this situation now"), cf. the discussion on marginal utility of scope in Ojea and Loureiro (2011). Hensher et al. (2005) found a decreasing marginal WTP to reduce the frequency of water service interruptions, with the possible explanation that an increase in the number of interruptions motivates people to take action to mitigate their impact. An increasing marginal dis-utility is also conceivable ("enough is enough – now we do not have any patience left to handle this situation"), but only 5 percent of the respondents stated that they were willing to pay *more* to avoid a second occurrence.

Do earlier studies on similar drinking water issues shed any light on the results? This is not easily analyzed; comparing absolute WTP estimates from different valuation studies is challenging for the same reasons that limit benefit transfer opportunities. These challenges are due to differences in factors such as population and study site characteristics, the change subject to valuation and the policy context. However, related stated preference studies also using the water and sewerage bill as the payment vehicle exist, which allows for comparisons that might be more informative. For instance, Genius et al. (2008) found that, in Rethymno (Greece) the WTP of residents for obtaining a continuous water supply and improved water quality, which would be accomplished through future projects by the water and sewerage authority, was 17.67 percent of their *quarterly* water bill (equivalent to EUR 10.64/household/quarter). Another stated preference study carried out in Greece is Latinopoulos (2014), in which the average WTP for decreasing the frequency of water supply interruptions was estimated to be approximately 5 percent of the current *annual* water bills (equivalent to EUR 12/household/year). These two studies were similar to our situation A (total outage in tap water delivery), except that the WTP estimate in Genius et al. (2008) also incorporated water quality improvements. A different study by Griffin and Mjelde (2000) imposes valuation scenarios more similar to situation C (water use restrictions). In one of their scenarios, they ask Texas residents about their WTP for expanding the community's water supply system to improve water supply reliability and thereby avoid future cuts. The results show a WTP equal to 22.2 percent and 25.6 percent of the respondents' mean *monthly* water bills (equivalent to USD 8.47–

9.76/household/month). In all three of these cases, respondents were asked to state WTP as a permanent increase in the water and sewerage bill.

In Section 3.1, we found that Swedish households were, on average, willing to pay around 100–300 percent of their average monthly water and sewerage bill as a one-time payment to avoid situations A, B, and C. The different policy contexts and water aspects being valued between this study and those mentioned above imply that the variation in WTPs as percentages of bill amounts cannot be explained easily, but it is worth noting the variation in the frequency and duration of payment for respondents' WTP. While it has been repeatedly demonstrated that respondents in stated preferences surveys show less sensitivity to the time frame of payment than what could be expected from a theoretical point of view (Myers et al., 2017), it is still reasonable to assume that one reason for the relatively high percentages found in the present study is the effect of asking respondents to state their WTP as a one-time payment rather than a perpetuity payment. Looking at the WTP estimates from Genius et al. (2008), Latinopoulos (2014) and Griffin and Mjelde (2000), we observe another intuitive pattern: the WTP expressed as a percentage of the water and sewerage bill increases with bill payment frequency. This also makes sense, since a higher frequency of bill payments normally implies a lower absolute value of each payment.

As to budget sequence sensitivity, a sequential formulation of the budget restriction did not have any significant impact on the WTP in relation to a non-sequential one in this study, though there was a weak tendency to such an impact for high-income respondents. Overall, this indicates that the sum of WTP amounts for situations A, B, and C that are conditional with respect to the impact on the budget restriction would not differ significantly from the sum of unconditional WTP amounts. In general, adding unconditional WTPs is likely to cause an overestimation of total WTP (cf. the inequality after Equation (3)), which suggests a danger of uncritically adding together WTP estimates from different studies (Hoehn and Randall, 1989; Johansson and Kriström, 2016). However, if the change being valued is truly marginal with respect to market prices and/or non-market values, aggregation of unconditional WTPs would not differ from aggregation of conditional WTPs (Johansson and Kriström, 2016). It is empirically challenging to conclude whether a valued change is marginal or non-marginal, but we interpret the test of the impact of the budget restriction formulation as an indication that, for situations A, B, and C, we are generally dealing with marginal changes and that the WTPs for these situations can be summed together without violating respondents' budget restrictions. Note that the test was strong in the sense that it was done for the longest duration times of each of the A, B, and C situations.

The validity of the test on the impact of the way of formulating the budget restriction hinges on the assumption that respondents were actually reading and considering the text about the budget restriction when they responded to the WTP questions; this cannot always be taken for granted, which is indicated by mixed empirical results regarding the impact of budget reminders on stated values (Sælensminde, 2003). However, one might interpret the tendency among high-income respondents to show budget sequence sensitivity as an indication that the budget restriction text was read and understood. Summing the mean WTP point estimates across situations for the longest duration times results in a household WTP of about SEK 4,000. This is about 8 percent of the mean monthly after-tax household income of about SEK 50,000. While this appears to be a substantial percentage, recall that the respondents were asked for a one-time payment. A considerably lower percentage would probably emerge if respondents had instead been asked about a monthly WTP over a specified time period, e.g., 12 months. However, as noted above, the magnitude of this reduction is not necessarily in line with theoretical expectations.

4.2 Risk valuation and efficiency vs. equity issues

One of the ultimate purposes of estimating benefits is to give input to CBA to support decision-making. Two aspects related to this will be discussed here: (i) the use of estimates of the benefits related to avoiding undesired consequences in a risk-based approach to drinking water management, and (ii) equity issues that might arise when using the benefit estimates in CBA.

The first aspect is about the fact that measures preventing situations A, B, and/or C will typically be about reducing the *risks* associated with such situations, i.e., a CBA of such measures must consider the probability of such occurrences. However, the WTP estimates in this study are limited to the benefits of avoiding *consequences* and give no information about the respondents' preferences in a probabilistic context. In a CBA of risk-reducing measures, a risk valuation could still be obtained by multiplying the estimated WTP to avoid a situation with estimates of the probability of occurrence based on historical data, expert judgments, or modeling results (Boardman et al., 2018). Such a risk valuation *ex post* can be described as paternalistic, which might be justified if people tend to systematically misperceive the probabilities of some events (Shaw and Woodward, 2008). Risk research has generally concluded that people tend to overestimate the risk of events with small probabilities and underestimate the risk of high probability events (Wolff et al., 2019).

On the other hand, the principle of consumer sovereignty advocates that people's individual preferences with respect to both consequences and probabilities should be respected when assessing what is beneficial to society and what is not (Johansson and Kriström, 2018). This suggests a risk valuation *ex ante*, i.e., an option price approach where preferences with respect to both probabilities and consequences are investigated (Shaw and Woodward, 2008; Freeman III et al., 2014). However, including a probabilistic context in a valuation scenario is challenging to communicate to respondents (Logar and Brouwer, 2017). In the context of this study, the information available on the probabilities of situations A, B, and C in different parts of Sweden was too limited to assume well-informed households or to present such probabilities to respondents. That is, the current knowledge of probabilities for carrying out risk-based CBAs in Sweden needs to be improved, regardless of what risk valuation approach is viewed as the most suitable one. In addition, it should be noted that groups other than households rely on the drinking water supply, and they might also benefit from risk-reducing measures. For example, source water protection could safeguard the provision of multiple services to society, including water for agricultural purposes, energy production, recreational activities, and much more (Gärtner et al., 2022).

As to the second aspect – equity issues when using benefit estimates in CBAs – it should first be noted that the municipalities in Sweden are by law responsible for managing the drinking water supply. In total, there are 290 municipalities, of which about 65 percent operate the water supply within their municipality, and the rest are involved in different kinds of inter-municipal cooperation (Sjöstrand et al., 2019). Consequently, decisions about drinking water management are often made under substantially varying conditions in terms of, e.g., land area, environmental and technical conditions, political majority, and socio-demographic conditions such as population size and household income (see Section 3.3).

Now, consider a low-income and a high-income municipality using CBA as decision-support to evaluate measures in the respective municipality. Assume that the measures would result in a similar risk reduction to the drinking water system for a similar number of consumers and for similar costs. Note that there is no reason a priori to assume that the measures would be achievable at a lower cost in a low-income municipality than in a high-income one; rather, the costs are dependent on local natural conditions, such as access to alternative water sources and preconditions of the technical system. This is supported by the fact that data do not indicate any positive correlation between water and sewerage rate and average household income in Swedish municipalities (see SM1.11 for details); recall from Section 1 that the Swedish Water Services Act (SFS, 2006) requires the rate to be based on cost recovery and the rate is therefore usable as a proxy variable for costs. The results in Section 3 showing that income had a positive effect on WTP suggest that the aggregate benefits of the measures would be lower in the low-income municipality than in the high-income one, potentially causing a negative net present value in the former and a positive net present value in the latter. The recommended decisions based on these results, i.e., to implement the measure in the wealthy municipality but not in the poor one, would be perfectly accurate from an economic efficiency point of view. However, would it be fair to only let the residents in the wealthy municipality enjoy the risk reduction? This is an enduring question, which can be highlighted thanks to valuation studies and CBA when their capacity to show distributional effects is properly utilised (Cecot, 2023).

The equity issue might be approached by introducing distributional weights in the CBA, thus acknowledging a declining marginal utility of income (Hammitt, 2013; Cecot, 2023). In practice, this option is usually not applied in CBA (Nurmi and Ahtiainen, 2018), and intricacies in establishing weights could potentially cause decision-makers to simply conclude that situations where the benefit of a measure depends on income should be avoided because of potentially inequitable outcomes. If so, one option might be to make use of a national average – as opposed to municipal-specific – WTP, such as the estimates reported in Table 3, Table SM1.4.3 and the last three rows of Table 4. However, this might not be enough to create more equitable outcomes because measures are to be funded by the water and sewerage rate whose level is decided by each municipality based on cost recovery. In general, smaller municipal water systems encounter difficulties in achieving cost reductions per household through economies of scale (Cecot, 2023). In the context of Sweden, low-income municipalities in rural and sparsely populated areas are indeed expected to face the largest future increases in the water and sewerage rate (SWWA, 2021; de Fine Licht, 2023). The relatively low ability to pay in low-income municipalities might thus imply a financial obstacle to equitable implementation. One solution might be inter-municipal redistribution of resources, such as extending the existing Swedish municipal equalization system to take drinking water issues into full account (Syssner and Jonsson, 2020). There is currently a public debate in Sweden regarding this option (SWWA, 2023c). Note, however, that low-income households might still be more likely to incur a net loss in wellbeing because Sweden – unlike most OECD countries – has no mechanism to address affordability issues for water and sanitation services (OECD, 2021). Although the Swedish Water Services Act requires water and sewerage rates to distribute costs "fairly" (SFS, 2006, 37 §), fairness has so far been interpreted as proportionality to consumption of water services and to water utilities' connection costs, rather than as affordability (de Fine Licht, 2023). With rising investment needs in drinking water infrastructure, equity concerns – both inter-municipal and intra-municipal – are likely to receive increasing attention.

5 Conclusions

This contingent valuation study contributes to enabling CBAs of measures that could prevent disturbances in municipal drinking water supply by estimating the benefits associated with Swedish households' WTP to avoid three different undesired events, each with three different duration times: (A) a total outage of tap water delivery (24 hours, 1 week, 1 month); (B) tap water is delivered but must be boiled to be fit for drinking (24 hours, 1 week, 1 month); and (C) tap water is delivered but restrictions are imposed against particular uses of tap water because of a need to reduce total water consumption (1 month, 3 months, 6 months).

On average, the households have a positive WTP for extra investments in preventive measures that would help avoid situations A, B, and C for all studied duration times. National mean WTP estimates are robust in the sense that parametric estimation through three alternative regression models, and non-parametric estimation, yield similar results. In addition, household income was found to have an expected positive and significant effect on WTP. The main regression model resulted in the following estimates of mean one-time household WTP (Table SM1.4.3), expressed in 2022 euro and rounded to the nearest ten: EUR 90 (A, 24 hours); 130 (A, 1 week); 130 (A, 1 month); 60 (B, 24 hours); 120 (B, 1 week); 130 (B, 1 month); 110 (C, 1 month); 100 (C, 3 months); and 120 (C, 6 months). However, due to scope insensitivity with respect to duration time (see Section 4.1), the estimates for the longest duration of situations A and B (1 month) are not recommended for policy purposes. Scope insensitivity is also present for situation C, but for this situation, it might be reasonable to assume that households regard the longer durations as not being more cumbersome than the shortest one.

In two subsamples using a sequence of WTP questions, two different instructions were communicated to respondents with respect to how they were to consider the impact of their stated WTP on their budget restrictions: either fully (i.e., a sequential budget restriction) or not at all (i.e., a non-sequential budget restriction). Overall, the two treatments gave similar results, which indicates that separately estimated WTPs for the three situations A, B, and C can be summed without violating respondents' budget restrictions.

Finally, whether decision-makers should rely on the national mean WTP estimates mentioned above, or use the municipal-specific mean WTP estimates based on the tailored model in Section 3.3 (see Table 4 for examples), when performing CBAs of investments that could prevent the situations, depends on considerations about efficiency vs. equity.

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