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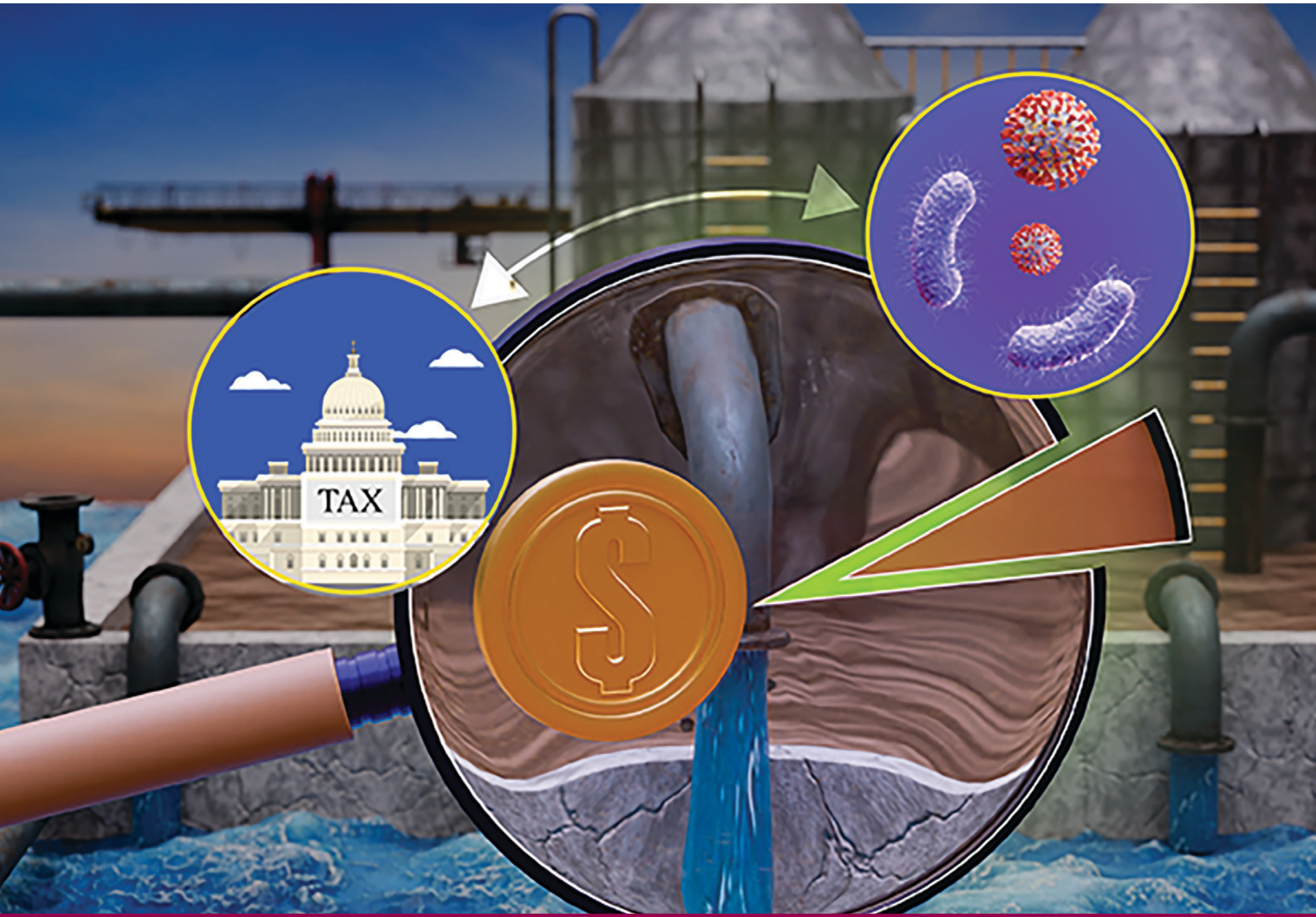

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Willingness to pay for nationwide wastewater surveillance system for infectious diseases in Japan†

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COVID-19 motivated the US and the European Union to establish a regular pathogen surveillance system at wastewater treatment plants, but other countries, including Japan, have been reluctant to adopt such a system. To determine whether a continuous pathogen surveillance system at wastewater treatment plants is economically justifiable in Japan, we conducted a contingent valuation experiment to estimate a hypothetical willingness to pay (WTP) for such a surveillance system. To collect primary data, an online WTP experiment was administered to a nationally representative sample in Japan in spring 2023 (N = 2457). Results indicated that mean WTP was US $23.47 (Median $8.83) per household per year, and that around 97% of individuals had a non-zero WTP. The monetary valuation aggregated to the national level ($497 million based on the median value) exceeds the likely costs of maintaining the system in Japan ($33 million). Based on the population's valuation of the nationwide wastewater surveillance system, its establishment would be economically justifiable in Japan. Our results are expected to inform stakeholders in Japan, the US, the European Union, and other countries considering expanding or maintaining wastewater surveillance systems that are applicable for diverse infectious diseases including COVID-19. For a future epidemic with uncertain risks, the surveillance systems' economic efficiency (*e.g.*, cost-effectiveness and return-on-investment) is difficult to assess. Eliciting taxpayers' WTP can be informative for that purpose.

Water impact

Providing economic information to stakeholders could support the rationale behind implementing or continuing large-scale pathogen surveillance at wastewater treatment plants. For a potential future epidemic with uncertain risks, accurately simulating or predicting the wastewater surveillance system's "return on investment" proves challenging. However, this study demonstrates that such uncertainty can be mitigated through willingness-to-pay estimates elicited from taxpayers.

1 Introduction

Since the year 2000, the global society has experienced two pandemics (*i.e.*, H1N1 influenza and COVID-19) and more than ten major epidemics, *e.g.*, SARS,[1] which demonstrates the need to allocate more resources towards strengthening an epidemic surveillance system globally. Epidemic data based on regular wastewater surveillance at wastewater treatment plants (WWTPs)[2] have relative advantages over clinical surveillance: higher representativeness (*i.e.*, capturing epidemic status in a community without selection bias in seeking clinical tests), higher testing capacity (*i.e.*, unlike limited access to clinical tests during epidemic peaks), and much lower cost for population-level pathogen surveillance.

COVID-19 motivated most developed countries to establish a regular surveillance system at WWTPs, *e.g.*, implemented at

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more than 1700 and 1300 sites in the US[3] and the European Union (all cities with a population >150 000),[4] respectively. Nonetheless, other countries have been reluctant to adopt this system, *e.g.*, less than twenty cities in Japan have continued to implement and publicly release WWTP-based epidemic data.

To inform the discussion about further expanding the use of regular surveillance systems at WWTPs globally, two types of economic considerations could be relevant to stakeholders. The first consideration relates to the system's economic efficiency, expressed with "incremental cost-effectiveness ratio", "benefit to cost ratio (BCR)/return on investment (ROI)", or "net benefit in monetary values". Estimates of these economic indicators were provided by previous simulation studies using the observed risk and benefit parameters concerning COVID-19.[5,6] However, these simulation estimates are not directly applicable for other pathogens, particularly a future epidemic with unknown risks. This limitation of the first type of information can be addressed partly by the second type of economic information, *i.e.*, population preferences regarding the willingness to pay (WTP) for such a system. For public investments, this information is often derived from contingent valuation experiments, aiming to elicit the overall monetary value for a non-market (or public) good among taxpayers.[7]

In a previous study, the WTP for a hypothetical and generic early warning system for infectious diseases and foodborne outbreaks was estimated among six European countries.[8,9] This study was conducted before (2018) and after (2020) the onset of COVID-19. They found that the median WTP was €10 per household per month in 2018, which increased by 30% in 2020. Since they reported large WTP differences across countries, their WTP estimates seem difficult to extrapolate for other countries.

Our study aims to estimate the WTP for a hypothetical nationwide wastewater surveillance system for infectious diseases in Japan. We also want to test the hypothesis, whether the budget for maintaining this system in the major cities of Japan, which was estimated to be 33 million US dollars ($) (ESI† S1[6]), would be lower than the WTP elicited among a nationally representative sample. Compared to similar studies in Europe,[8,9] our study is expected to contribute to the literature by dealing with a specific surveillance system (with a specific target budget amount to compare with WTP), including individuals aged 65 or older, who are generally more at risk from COVID-19 and future epidemics, and having been conducted in 2023, when effective vaccines and treatments for COVID-19 were available.

2 Materials and methods

2.1 Survey administration

We conducted contingent valuation experiments among the general population in Japan. A professional sampling institution recruited participants (aged >19) from its existing online panel (aiming to have a nationally representative sample while also including individuals from all 47 prefectures) and fielded an online survey in March 2023. Participants completed the survey using a computer or mobile device, and received a coupon for online shopping when finished. Participants consented to their anonymous responses being used for research purposes. At the beginning of the survey, participants had to consent to their anonymous responses being used for research purposes. This study received an ethical approval from the Ethical Review Committee at Kanagawa University of Human Services (2022-36-012-SHI-55; approved on January 16, 2023). All procedures were performed in compliance with the institutional guidelines.

2.2 Survey design

Our survey design generally followed the previous surveys used to elicit values for the warning system for infectious diseases and foodborne outbreaks in European countries.[8,9] Key features of our survey design regarding the contingent valuation experiment were illustrated in Fig. 1. Our survey started with an introduction of the topic and questions about respondents' gender, age, marital status, awareness of outbreaks, and COVID-19 infection experience (see ESI† S2). The choice of a payment card WTP elicitation format, which was frequently applied when valuing health safety,[10] over a dichotomous choice format was motivated by aiming to avoid exaggerated WTP values due to yea-saying.[11]

Subsequently, the questionnaire included a warm-up exercise eliciting the WTP for a common market good, *i.e.*, an umbrella, aiming to help respondents become familiar with the process. Thereafter, respondents stated their WTPs for the proposed surveillance system, as an annual tax. Eliciting the WTP followed a two-stage procedure. The first stage asked respondents for a value they would definitely pay (the "lower interval") and a value they would definitely not pay (the "upper interval"). The second stage asked the actual valuation between the intervals responded in the first stage by the same individual. This procedure aimed to provide precise and direct maximum WTP valuations and to reduce midpoint bias and scale sensitivity.[8]

More specifically, the first stage's initial step asked respondents to choose the "lower interval" using a payment scale ordered from low to high Japanese Yen values. These values, converted to purchasing power parity (PPP) adjusted 2023 US dollars (USD),[12] were (0, 0.11, 0.22, 0.33, 0.55, 1.10, 2.20, 3.30, 5.50, 11, 22, 33, 55, 110, 165, 220, more than 220). When "more than 220" was chosen, a respondent was required to indicate a value higher than 220 in the following open-ended question. When a maximum WTP of zero was chosen, respondents had to choose one of four pre-specified reasons: not worth more than 0, unable to pay more than 0, government task, and other (with an open text field). Under the first stage's second step, the respondents who chose a value between 0.11 and 220 were asked to choose the "upper

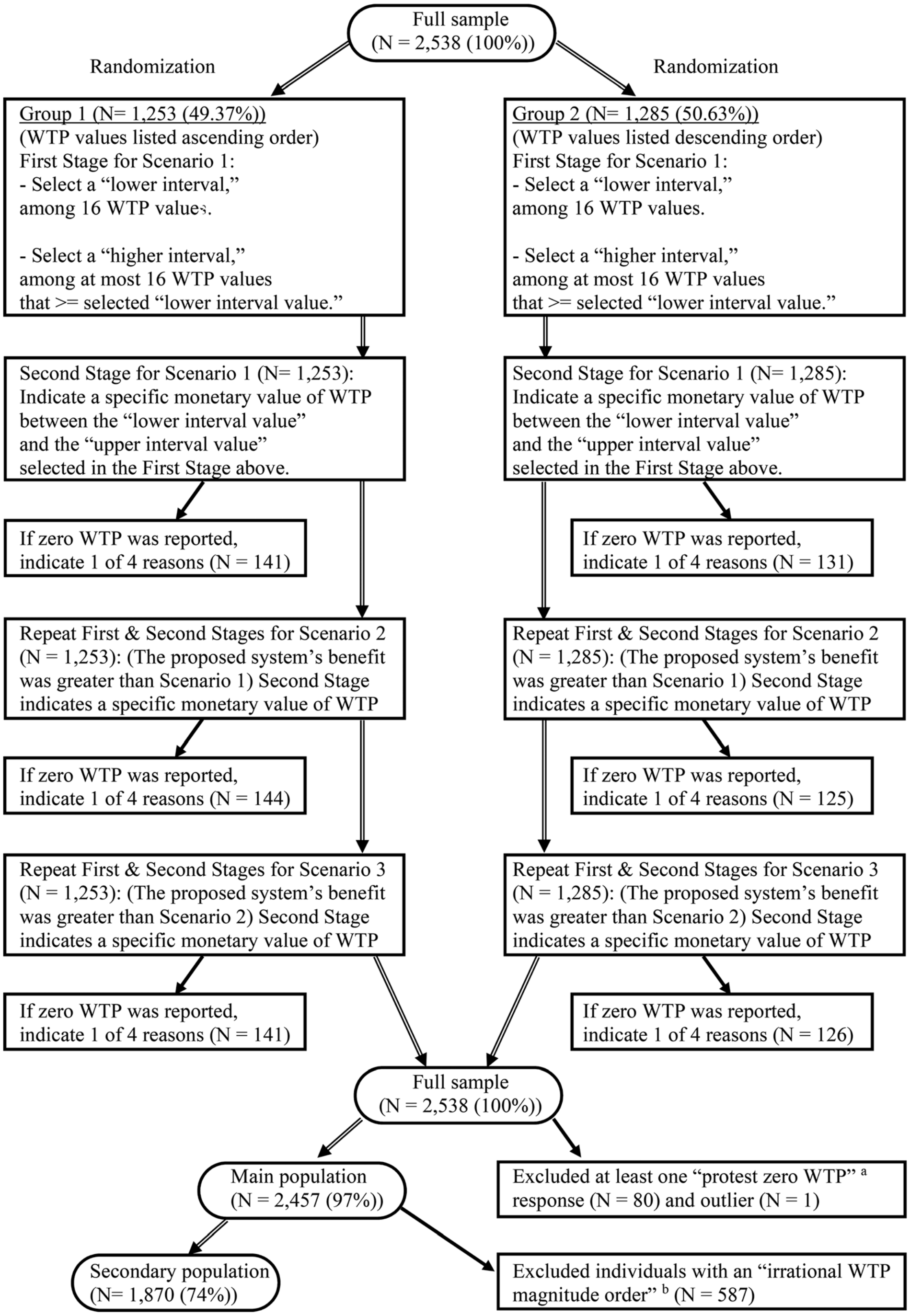

Fig. 1 Study design of the contingent valuation experiment. Abbreviation: WTP, willingness to pay. [a] "Protest zero WTP" was one of 4 reasons listed, *i.e.*, "government task." [b] "Irrational WTP magnitude order" was defined as either "WTP for scenario 1 > WTP for scenario 2", "WTP for scenario 1 > WTP for scenario 3", or "WTP for scenario 2 > WTP for scenario 3". Three scenarios varied in terms of the effectiveness of the proposed surveillance system: mortality will decline from 10% to 8%, 5%, and 2% under scenario 1, 2, and 3, respectively.

interval" among the same payment scale, excluding values below the "lower interval" chosen in the initial step. Together, these two steps produced a WTP interval. Within this interval, the second stage asked the exact amount that respondent would be willing to pay per year. This represents the final elicited WTP used for the analysis. To assess the impact of either ascending or descending order of monetary amounts on the payment scale on WTP, the order was randomized across respondents.

WTP values were elicited for three scenarios which included the same explanation about the general benefit of the proposed system, *i.e.*, mitigating and controlling an epidemic of infectious diseases, such as COVID-19 and influenza. The scenarios, however, differed in terms of the system's hypothetical effectiveness: the assumed baseline infection rate is set to decline from 10% to 8%, 5%, and 2% under scenarios 1, 2, and 3, respectively. It was described to respondents that these infection rates relate to a viral infection, with similar morbidity and mortality as COVID-19 (ESI† S2).

Finally, respondents were asked about their health status, smoking status, occupation, education, and income. Additionally, using a 5-point Likert scale, the questionnaire asked about comprehension of the overall questionnaire, the proposed surveillance system, and the perceived feasibility regarding the proposed system's effectiveness.

2.3 Pilot surveys

Two pilot questionnaire surveys were conducted in March 2023 prior to implementing the main survey. The validity of responses was mainly assessed based on the proportion of an irrational order of WTP estimates for the three scenarios within an individual. An "irrational order of WTP responses" violated the expected order of WTP responses across the three scenarios, *e.g.*, if WTP in scenario 1 (two percentage points infection rate reduction) was higher than WTP in scenario 2 (five percentage points reduction). The proportions of individuals with at least one pair of irrational responses were 39% and 29% in the first (N = 125) and the second pilot survey (N = 143), respectively. In the first pilot survey, the order of the three scenarios was randomized, which lead to lower comprehension levels about the overall questionnaire. To reduce this proportion and to obtain more internally consistent results, the order of the scenarios in the second pilot survey was ascending in risk reduction (1, 2, 3). Following more consistent estimates, this order was then implemented in the main survey. Due to the changes in the survey design, the pilot survey samples were not included in our full sample or any data analysis.

2.4 Data analysis

In addition to descriptive analyses of the WTP values, linear regression analyses were conducted to assess correlations with WTP values. Covariates in multivariate analyses mainly followed the previous studies.[8,9] WTP served as the dependent variable. The three WTP responses from each respondent were simultaneously included to perform pooled regression analyses, accounting for correlations due to individual specific factors as a cluster. All data analyses used STATA 17.0 (Stata Corp. 2021. Stata Statistical Software: Release 17. College Station, TX: Stata Corp LP).

3 Results and discussion

3.1 Sample characteristics

The total number of completed survey responses was 2538. The completion response rate was 7.04% among 36 026 individuals who received an invitation to this survey. This full sample's characteristics are shown in Table 1.

Table 1 Descriptive statistics among the full sample, the main population, and the secondary population

	Full sample (N = 2538)	Main population[a] (N = 2457)	Secondary population[b] (N = 1870)
	Mean (SD)	Mean (SD)	Mean (SD)
Annual household income [1000 US dollars]	61.32 (44.01)	61.63 (44.24)	61.53 (44.13)
Age	54.07 (14.92)	54.15 (14.97)	54.27 (14.63)
Female[c]	0.50 (0.50)	0.51 (0.50)	0.51 (0.50)
2-year college or higher educational attainment[c]	0.61 (0.49)	0.61 (0.49)	0.61 (0.49)
Married[c]	0.59 (0.49)	0.59 (0.49)	0.59 (0.49)
Employed, excluding self-employed[c]	0.60 (0.49)	0.60 (0.49)	0.59 (0.49)
Self-employed[c]	0.09 (0.28)	0.09 (0.28)	0.10 (0.30)
Not employed[c]	0.40 (0.49)	0.40 (0.49)	0.41 (0.49)
Health status[c,d]	0.16 (0.37)	0.16 (0.37)	0.17 (0.37)
Awareness of outbreaks[e]	43.02 (6.09)	43.05 (6.06)	43.08 (5.93)
No COVID-19 infection experience for oneself or family[c]	0.68 (0.47)	0.68 (0.47)	0.69 (0.46)
COVID-19 infection experience for oneself[c]	0.06 (0.23)	0.06 (0.23)	0.05 (0.22)
COVID-19 infection experience both for oneself and family[c]	0.17 (0.37)	0.17 (0.37)	0.16 (0.36)
Ever smoking status[c]	0.35 (0.48)	0.35 (0.48)	0.34 (0.48)
Mortality rate of COVID-19 [per million in a resident prefecture]	580 (160)	578 (159)	578 (158)
WTP order[f]	0.51 (0.50)	0.51 (0.50)	0.51 (0.50)

Abbreviation: SD, standard deviation; WTP, willingness to pay. [a] Main population excluded outliers (defined as WTP exceeding 5% of annual income (N = 1)) and all individuals with at least one protest zero in any of 3 scenarios (protest zeros) from the full sample. [b] Secondary population further excluded those who responded with at least one pair of "irrational WTP magnitude order" from the main population. "Irrational WTP magnitude order" was defined as either "WTP for scenario 1 > WTP for scenario 2", "WTP for scenario 1 > WTP for scenario 3", or "WTP for scenario 2 > WTP for scenario 3". Three scenarios varied in terms of the effectiveness of the proposed surveillance system: mortality will decline from 10% to 8%, 5%, and 2% under Scenario 1, 2, and 3, respectively. [c] Dichotomous variable. [d] Best or second-best level of subjective general health status among 5 levels. [e] Awareness of outbreaks, scored from 12 to 60, 12 questions with 5 levels. [f] WTP order: 1 if WTP values presented from high-to-low in a survey; 0 if WTP values presented from low-to-high in a survey.

Table 2 Percentage of responses with WTP of zero[a]

	Total zeros	"True zero WTP"		"Protest zero"
		Not worth it	Unable to pay	Govt. task + protest
% Share of zeros	100.0	60.5	15.0	24.5
% Share of all responses	10.6	6.4	1.6	2.6

Abbreviation: WTP, willingness to pay. [a] There are 7614 WTP responses from 2538 individuals answering in 3 scenarios. Among 7614 WTP responses, 808 (10.6% of 7614) responses were "WTP of zero". Eighty respondents reported at least one "protest zero" response. Fifty-five respondents consistently reported a "protest zero" in all three scenarios, and 25 respondents reported "protest zero" only in either one or two of the three scenarios.

3.2 Zero-WTP responses

There were 7614 WTP responses from 2538 individuals answering for the three scenarios. Among these 7614 WTP responses, 10.6% (808) responses were WTPs of zero (Table 2). Of these 808 responses, 60.5% (489 responses) were categorized as "not worth it", including responses with the pre-specified reason "not worth it" (408 responses), responses with a qualitative reason similar to "not worth it" (4 responses), and responses not indicating a reason (77 responses). Those with the pre-specified reason "unable to pay" were 15.0% of all zero WTPs. The two categories of "not worth it" and "unable to pay" were treated as "true zero WTPs".

The remaining category of "protest zero" represented 24.5% (198 responses) of all zero WTPs, consisting of those with the pre-specified reason "government task" (184 responses) and those with a similar reason to "government task" in the open-text field (14 responses). Eighty respondents, with at least one "protest zero" response, had significantly lower income (p = 0.014), compared to respondents without any "protest zero" response.

3.3 WTP estimates

The population WTP was estimated for two separate study populations: the first population, hereafter named main population, excluded respondents with at least one "protest zero" response (N = 80) and outlier observations (N = 1) from the full sample (N = 2538). "Outlier" was defined as reporting a WTP that was greater than 5% of a respondent's income. The secondary study population additionally excluded individuals with an "irrational order of WTP responses" (N = 587). Individuals with an "irrational order of WTP responses" were more likely to report significantly lower levels of comprehension regarding the overall survey questions (p = 0.001) and the proposed surveillance system ($p < 0.001$).

In the first stage, the values for the "lower interval" ("definitely be willing to pay") had a mean of $9.85 (SD 18.76) and a median of $3.74 among the main population (ESI† Table S5). The mean of the "upper interval" ("definitely not willing to pay") was $26.00 (SD 35.91) with a median of $7.47. The second stage provided a mean stated WTP of $23.47 per household and a median WTP of $8.83, as shown in Table 3. The corresponding standard deviation of $44.29 implies a substantial heterogeneity. When aggregating this median WTP to the national level, assuming 93.3%[13] of all households (60.3 million) are eligible for income taxation,[14] the tax volume would amount to $497 million per year. Compared to the main population, WTPs among the secondary population had a slightly lower mean, median, and standard deviation (Table 3).

3.4 Potential determinants of WTP

Table 4 contains coefficient estimates for the regression analysis pooling WTP estimates from all three scenarios. Positive WTP predictors ($p < 0.05$) were income, education, and higher levels (3rd and 4th quartiles) of awareness of outbreaks among the main population. Increased age was estimated to have a negative effect on WTP for individuals, but at a decreasing rate in older

Table 3 WTP per year in US dollars for 3 sample populations

Category	Mean (SD)	Median	Min	Max
Full sample (N = 2538)	22.95 (44.41)	7.72	0.00	1104
Main population[a] (N = 2457)	23.47 (44.29)	8.83	0.00	1104
Secondary population[b] (N = 1870)	20.48 (42.11)	6.62	0.00	1104

Abbreviations: WTP, willingness to pay; SD, standard deviation. [a] Main population excluded outliers (defined as WTP exceeding 5% of annual income (N = 1)) and all individuals with at least one protest zero in any of 3 scenarios (protest zeros) from the full sample. [b] Secondary population further excluded those who responded with at least one pair of "irrational WTP magnitude order" from the main population. "Irrational WTP magnitude order" was defined as either "WTP for scenario 1 > WTP for scenario 2", "WTP for scenario 1 > WTP for scenario 3", or "WTP for scenario 2 > WTP for scenario 3". Three scenarios varied in terms of the effectiveness of the proposed surveillance system: mortality will decline from 10% to 8%, 5%, and 2% under scenario 1, 2, and 3, respectively.

Table 4 Pooled regressions on WTP for main and secondary populations

	Main population[a]		Secondary population[b]	
	Coefficient (SD)	p value	Coefficient (SD)	p value
Log income	15.44 (2.81)	***	17.28 (3.38)	***
Age	−1.10 (0.41)	***	−1.13 (0.51)	**
Age-squared	0.012 (0.004)	***	0.013 (0.005)	***
Female	−3.96 (2.13)	*	−2.38 (2.47)	
Education – 2 year college or higher	3.81 (1.69)	**	4.15 (1.93)	**
Married	−0.63 (2.08)		−1.77 (2.48)	
Self-employed	−3.48 (2.85)		−2.91 (3.15)	
Not-employed	−2.90 (2.00)		−2.74 (2.34)	
Health status[c]	3.68 (4.06)		6.10 (4.92)	
Awareness 2nd quart.[d]	−1.59 (2.72)		−1.35 (3.33)	
Awareness 3rd quart.[d]	7.67 (3.15)	**	8.58 (3.78)	**
Awareness 4th quart.[d]	12.85 (3.22)	***	12.49 (3.95)	***
No COVID-19 infection experience	−2.30 (2.08)		−1.22 (2.49)	
Mortality rate of COVID-19 [per million in a resident prefecture]	0.003 (0.009)		0.005 (0.011)	
Smoke ever	0.03 (2.39)		−1.37 (2.88)	***
Scenario 1[e]	−1.14 (0.36)	***	−3.47 (0.30)	***
Scenario 3[e]	2.12 (0.43)	***	4.08 (0.47)	***
WTP order[f]	8.78 (1.78)	***	8.56 (2.13)	***
Constant	−34.92 (20.1)	*	−47.19 (25.2)	*
Observations	7371		5610	
R-squared	0.0549		0.0569	
Root MSE	46.09		47.37	

Abbreviations: WTP, willingness to pay; SD, standard deviation. [a] Main population excluded outliers (defined as WTP exceeding 5% of annual income (N = 1)) and all individuals with at least one protest zero in any of 3 scenarios (protest zeros) from the full sample. [b] Secondary population further excluded those who responded with at least one pair of "irrational WTP magnitude order" from the main population. "Irrational WTP magnitude order" was defined as either "WTP for scenario 1 > WTP for scenario 2", "WTP for scenario 1 > WTP for scenario 3", or "WTP for scenario 2 > WTP for scenario 3". Three scenarios varied in terms of the effectiveness of the proposed surveillance system: mortality will decline from 10% to 8%, 5%, and 2% under scenario 1, 2, (reference category in this regression) and 3, respectively. ***: $p < 0.01$; **: $p < 0.05$; *: $p < 0.1$. [c] Best or second-best level of subjective general health status among 5 levels. [d] Awareness 2nd/3rd/4th quart.: 2nd, 3rd, and 4th quartile of the awareness of outbreaks, scored from 12 to 60 based on 12 questions with 5 levels. [e] The three scenarios varied in terms of the effectiveness of the proposed surveillance system: mortality will decline from 10% to 8%, 5%, and 2% under scenario 1, 2 (reference category in this regression), and 3, respectively. [f] WTP order: 1 if WTP values presented from high-to-low in a survey; 0 if WTP values presented from low-to-high in a survey.

ages. More specifically, after age 47, an advancement in age was estimated to cause an increase in a WTP estimate. Also, the magnitude of this increase in a WTP was estimated to be greater with the advancement in age, as detailed in the ESI† S1. Similar findings were observed among the secondary population.

3.5 Effects of scenarios and study designs

As expected, the scenarios with a larger magnitude of the system's effectiveness were estimated to have larger mean WTP estimates. For instance, compared to the mean WTP for scenario 2 (five percentage points infection rate reduction; the reference in the regression model), the coefficient on scenario 3 (eight percentage points reduction) indicated that scenario 3's mean WTP was estimated to be $2.12 higher, after accounting for other covariates in the regression model, among the main population (Table 4). Similarly, the coefficient on scenario 1 (risk reduction of two percentage points) showed that its mean WTP was $1.14 lower than the mean WTP of scenario 2. The differences in WTP across scenarios were larger in the secondary population since this population excluded the individuals with an irrational order of WTPs.

The coefficient on the WTP order variable indicates that there was a significant difference in WTP due to the order the monetary amounts were shown in the payment scale in the elicitation task. In the main population, the mean WTP was $8.78 higher when amounts were shown in a descending order.

3.6 Comparison with past studies

Since our survey design and questionnaires mainly followed the previous studies in six European Union (EU) countries (EU experiments hereafter),[8,9] comparisons were made regarding the proportions of outliers and protest answers and the median values of WTPs. The proportion of outliers (WTP > 5% of income) in our study was only 0.04% (N = 1), which was much smaller than 4.8–5.4% in the EU experiments,[8,9] The proportion of protest answers was 2.6% in our study and 8.0–9.8% in the EU experiments.[8,9] Excluding these protest answers, the proportion concerning "true zero WTP" was 8% in Japan. In the EU experiment, it was 1.7–5%.[8,9]

Median WTP estimates in Japan ($8.83 per year) were much lower than those in the EU studies (corresponding to $157–$204 per year in PPP-adjusted 2023 US$[15,16]). Possible explanations for this difference are the following: first, we framed the payment as a yearly installment rather than a monthly one (used in the EU experiments). The effect of time framing on WTP is a known issue in WTP experiments,[17] with varying impact on results.[18] The choice for yearly installments was motivated by Japanese citizens being more familiar with yearly installments for similar fees/taxes. Second, the surveillance system described in our study had a narrower scope (*e.g.*, not including foodborne outbreaks) and entailed a more specific mechanism (*i.e.*, based on a wastewater surveillance). Third, a possible anchoring bias may have decreased our WTP estimates due to reference price information provided in the survey description (*i.e.*, $0.22 for earthquake monitoring systems and $55 for COVID-19 vaccination). Such reference points were not included in the EU experiments.[8,9]

Fourth, lower levels of public trust in the national government may have led to lower WTP estimates. According to the OECD trust survey, Japan was rated the second worst among the surveyed countries in terms of public trust in the national government.[19] Only 40% of respondents in Japan felt that their application for a generic government benefit or service would be treated fairly. This share was 58.5% for the OECD average and around 60–70% among Denmark, UK, and the Netherlands, which were part of the EU experiments.[8,9,19]

Finally, the difference in the survey timing could explain lower WTP estimates. In the EU experiments, the WTP estimates elicited during the onset of COVID-19, at a time of high uncertainty and fears in the population (spring in 2020), tended to be higher than those before COVID-19 (2018).[8,9] The responses in our study relate to spring 2023, where effective vaccines and treatments were already available. In a different study from Japan, a contingent valuation experiment was conducted to estimate WTP for epidemic information based on the already-established wastewater surveillance system in Sendai city.[20] Since their survey did not elicit WTP for establishing the surveillance system itself, their WTP estimates are not directly comparable to ours. However, their mean yearly WTP estimate of $3.48 for epidemic information implies reasonable face validity of our WTP estimates.

Face validity of our WTPs was also indicated by potential determinants of WTPs in our regression analyses. The directions of the associations of the significant coefficients, such as income, age, education, and awareness of outbreaks were consistent with the EU experiments.[8,9] Also, the logical order of the mean WTPs across three scenarios in our analyses aligned with other previous studies on WTP for general health services.[21]

3.7 Potential threats to validity

There are several potential threats to the validity of our study design and findings. Including COVID-19 in our survey description may have overestimated the potential benefits of the system that was assumed to operate for future infectious diseases as well, which are likely to have lower morbidity and mortality risks than COVID-19. This overestimation appears less serious since the elicited values in our survey also partly represent other benefits of such a system like the respondents' feeling of safety[8] as well as the perceived effectiveness in reducing risks for other diseases, *e.g.*, influenza, that was also included in our survey description.

As reported in subsection 3.5 and Table 4, our WTP estimates were significantly affected by a specific framing effect, *i.e.*, the order of WTP values in the questionnaire. Examining and incorporating this framing can be considered a strength of our study since a recent review paper pointed out that only a small number of previous studies empirically reported the potential framing effects in their regression analyses.[19] Our finding was consistent with a study by Smith (2006), indicating that an order of "values listed from high-to-low" produced significantly higher WTP values than the other order of "from low-to-high".[22] Since we were unable to conclude which order could yield less biased WTP estimates, we randomly assigned these two formats among respondents to at least obtain an overall assessment of the magnitude of the framing effect. We perceived this framing effect of the payment card method to be less of a concern than possibly exaggerated values due to "yea-saying" in the dichotomous choice format, which may be exacerbated when valuing goods for which respondents may have less well-formed preferences (as is the case for wastewater surveillance).[11]

Our WTP estimates could further be biased if respondents did not understand the WTP elicitation exercise and answering format. Such concerns may be alleviated by the following: first, a warm-up exercise eliciting the WTP for an 'umbrella' produced reasonable results, *i.e.*, median $11.04 (mean $22.19). Second, the proportion of zero-WTP was only 2.4% for the umbrella with certain and direct benefits, which was much lower than 10.6% for the surveillance system with hypothetical and indirect benefits. Third, a relatively small proportion (14.33%) of the respondents reported lower levels (lowest two levels among five levels) of comprehension about the overall survey questions among the main population. Excluding these 14.33% of respondents from the main population did not affect the median WTP estimate for the surveillance system.

Additionally, our recruiting and survey-response methods may have affected our WTP estimates. Our study's participants were recruited from an existing online panel and had to complete the survey using a computer or mobile device, which made our study participants different from the general population. For instance, our participants tended to include more educated individuals and not to include the oldest individuals. That is, regarding the proportion of 2-year college or higher educational attainment, it was 61.0–61.3% among our three study-populations which was higher than 45.4% among the general population.[23] Such higher educational attainment among the study participants could be partly because the oldest subpopulation (with lower educational attainment) did not participate in our survey. For example, 95 and 99 percentiles in age of our full sample were 75.0 and 82.0 years old, respectively. These values were much lower than the corresponding values of 85.4 and 92.6 among the national data, respectively.

It should be noted that these two factors (education and age) are expected to offset each other in their effects on WTP estimates, *i.e.*, a positive association with education and a negative association with age (>= 47 years old). Moreover, the education effect on WTP, which will be offset by the age effect, would be small in the magnitude in the following calculation. The estimated coefficient of the variable of "2-year college or higher educational attainment" was 3.81 among the main population (Table 4). Assuming a linear association between this education variable and WTP, our WTP estimate would be declined by \$0.61 (= \$3.81 × (61.3–45.4%)) when this education variable was set at 45.4% (of the general population) instead of 61.3% (of the main study population). When the median WTP value of \$8.83 was decreased by \$0.61 (*i.e.*, 6.9% of \$8.83), the national level WTP will decline from \$497 million to \$463 million which is still much larger than the likely costs of maintaining the system in Japan (\$33 million).

3.8 Implications

Our key findings from the main population were quite robust to the selection of analysis populations, *i.e.*, the secondary population and the full sample. Thus, our results imply that most residents in Japan appear to value the proposed nationwide wastewater surveillance system through additional taxation of \$8.83 per year. A progressive income tax is recommended because it is able to exempt the lower income individuals/households, who were more likely to report a WTP of zero. The aggregated WTP of \$497 million per year could not only cover the proposed wastewater surveillance system (\$33 million) at WWTPs focused in this survey, but also broader applications of wastewater-related surveillance at international airports (\$0.5 million at four major international airports).

4 Conclusions

Conducting a two-stage contingent valuation experiment, our study estimated the population's WTP for a hypothetical nationwide wastewater surveillance system for infectious diseases in Japan. The survey sample consisted of respondents from each of the 47 prefectures and was representative for the general population in Japan. Among the full sample and across scenarios, 10.6% of elicited WTP responses were \$0. Excluding individuals with protest answers and outliers, the elicited overall mean annual WTP per household was \$23.47 (SD \$44.29) with a median of \$8.83.

Multivariate regression analyses indicated that potential WTP predictors are income, age, education, and awareness of outbreaks, with the signs of the coefficients following expectations (providing some reassurance on the internal consistency of the WTP values). The regression analysis also showed that WTP values were affected by framing effects and the design of the experiment, as well as the hypothesized system's effectiveness in reducing an assumed infection rate. The estimated value aggregated to the national level (\$497 million) exceeded and, hence, justified the threshold budget level (\$33 million) to maintain the system.

The estimated values and their aggregation indicate that the perceived monetary value of such a system would by far outweigh the expected costs to launch and maintain the proposed wastewater surveillance system at WWTPs plus strategic locations such as international airports. To finance the system, a progressive income tax is recommended to exempt the lower income population.

Our results are expected to inform discussions among stakeholders in Japan and other countries that have been reluctant to launch or expand wastewater surveillance systems for COVID-19 and other infectious diseases. Also, these results would inform the discussion in the US and the EU when stakeholders consider reducing the budget for the ongoing extensive surveillance at wastewater treatment plants in the US and the EU.

Abbreviations

WTP	Willingness to pay
WWTPs	Wastewater treatment plants
BCR	Benefit to cost ratio
ROI	Return on investment
PPP	Purchasing power parity

Data availability

Data cannot be shared because of the sensitive nature of the questions asked in this study.

Author contributions

Byung-Kwang Yoo: conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – review & editing, visualization, supervision, project administration, and funding acquisition. Rei Goto: conceptualization, methodology, validation, and writing – review & editing. Masaaki Kitajima: conceptualization, validation, and writing – review & editing. Tomoko Sasaki: conceptualization, writing – review & editing, and visualization. Sebastian Himmler: conceptualization, methodology, validation, and writing – review & editing.

Conflicts of interest

Dr. Kitajima (a) previously received grants, patent royalty, consulting fees, and payment for lectures from for-profit companies and (b) has a pending patents, which were not for the present manuscript. There are no conflicts of interest to declare for all other authors.

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