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Self-selected intervals in psycho-physic experiments and the measurement of willingness to pay

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ABSTRACT

Standard elicitation approaches used to obtain quantitative information typically assume that individuals can provide a precise value. For unfamiliar (as well as familiar) goods, this is a strong assumption. We suggest the use of self-selected intervals, in which the shortest possible interval is a point, i.e. the standard case. To explore this idea we use a state-of-the-art psychophysics lab experiment (N=60), in which five specific sound environments were randomly inserted into a set of 31 pairwise comparisons to elicit the subjective value of reducing ambient noise. We found that valuation uncertainty, measured as the length of a self-selected interval, is independent of the psychophysical conditions. The length of the interval is determined mainly by the subjective value of improving the environment, independent of the level of noise. These results, according to our review of the literature, are new. Interval elicitation enables individuals to provide reasonably consistent rankings of environmental improvements, even if individuals find it difficult to pin down a precise value. Thus, self-selected interval elicitation seems to have merit.

1. Introduction

A key issue in any survey is the elicitation architecture, that is, how to elicit information from the respondent.[1] A compact survey of many issues in survey research, namely response errors and biases across formats is provided in McFadden et al. (2005). In this study, we focus on preference elicitation in surveys. A widely adopted method to elicit stated preferences for non-market priced goods and services is the contingent evaluation method (CVM). This approach collects and analyzes the answers to a hypothetical question regarding (typically) willingness to pay (WTP) for a given environmental good or service. The answers reflect a behavioral intention: the individual is willing to pay a specific amount to obtain the good or service (Mitchell & Carson 1989).

There are different methods for eliciting such answers; in general, a closed-ended or open-ended approach has been used (Johnston et al., 2017). Rather than asking the individual to state a point estimate or select between given brackets, we use a setup where the individual can self-select any interval of choice. Asking for an interval instead of a single point to elicit stated preferences responds to the diffused opinion that individuals are uncertain of their values for unfamiliar non-market goods and services and that they prefer to define a range of values that expresses their preferences rather than a single point estimate (e.g., Li & Mattsson (1995); Ready, Whitehead, & Blomquist (1995); Banerjee & Shogren (2014); Hanley, Kriström, & Shogren (2009)).

Uncertainty may compromise the ability to provide a value, for example, it may result in a non-response. How subjects construct values may be context-dependent (Payne, Bettman, & Schkade, 1999; Hanley et al., 2009). For unfamiliar goods, constructing a representative value is especially challenging. Arguably, there could be an advantage to allowing a range rather than a point (Mahieu, Wolff, Shogren, & Gastineau, 2017). We argue that a self-selected interval may reduce biases, provide a richer picture of response uncertainty, potentially increase response rates, and maintain a link to recent ideas on coherent arbitrariness (Ariely, Loewenstein, & Prelec, 2003; See also Belyaev & Kriström, 2015).

In this paper, we apply a self-selected interval to the value of a public good: noise reduction. To reduce uncertainties about the scenario, we use a controlled experiment in a psychophysics lab. Individuals are exposed to different sound environments at the Gösta Ekman Laboratory, Stockholm University, a leading research lab for studying the

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[1] Perhaps the closest literature to our general approach is the significant body of literature on psychology, statistics, and survey research that provides approaches to elicit probability distributions.

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senses. Such noise experiments have a long tradition in psychophysics, but, according to our review of the literature, this study is the first to use monetary valuations as the underlying metric. In a standard psychophysics experiment, individuals rank different sound environments on a numeric scale (e.g., 1–10). In this study, the sound environments were sampled from urban Stockholm; thus, the good under consideration was therefore familiar to the participants (i.e., Stockholm residents).

We ask two questions: (i) is there a dose-response relationship in an interval context? (i.e., will an increased noise level increase the WTP for avoiding it?) and (ii) what determines the length of the reported intervals? Is the length (a measure of individual uncertainty) independent of the level of noise?

The first question is relevant to verify the hypothesis of the presence of a dose-response relationship when the WTP is sensitive to the noise level, and if the adoption of self-selected interval captures this relationship.

With the second question, we verify the hypothesis of independence of the length of the interval from the sound level per se. This condition of independence is necessary to guarantee the absence of bias to assume the truth-telling condition (as shown formally in the following theoretical setup). Indeed, in this case, variations in the communicated interval will depend on the WTP independently of the sound level per se.

If these hypotheses are verified, in the presence of a dose-response relationship, the length of the interval is defined as function of the values that represent the preferences of the participants, without being affected by the level of sound per se. Such that the length of the intervals is the expression of the willingness to pay that they manifest in response to the level of sound. In this case, the interval is a true expression of the preferences of the participants.

The paper is structured as follows: before we present an overview of the literature in Section 2. We define our hypothesis and the theoretical setup in Section 3 and report the details of the experiment in Section 4. We demonstrate the presence of a dose-response relationship between the WTP for the residential environment sound improvement and the noise increasing in Section 5. In Section 6 the independence of the length of the interval from the level of noise is demonstrated. The paper concludes with our comments on our findings.

2. Literature review

The elicitation method is a crucial aspect of the survey research. The architecture adopted in different formats can imply response errors and systematic biases (McFadden et al., 2005). A great part of the potential biases that can emerge when we ask for a stated preference is related to difficulties that the responders encounter in exactly recalling or defining the response they are asked to provide. So they provide responses that are constructed following heuristics that can be biased or provide a non-response.

Among these response errors and biases, we can find anchoring, order effects, and focal responses. Besides, in a condition of uncertainty, the values provided can suffer from context-dependent (Payne et al., 1999; Hanley et al., 2009). The common factor of these issues is the role of the difficulty in providing an exact value (McFadden et al., 2005; Tourangeau, Rips, & Rasinski, 2000).

The literature provides evidence of the presence of these issues in monetary valuations. In experiments involving the selling of hypothetical lottery, a strong anchoring effect has been found in the stated willingness to accept (Chapman & Johnson, 1999). In financial decision-making, anchoring has been proven to play an important role, that increases under pressure (Jetter & Walker, 2017). Northcraft and Neale (1987) showed experimentally that these biases affect the monetary valuations provided both by experts and amateurs.

Uncertainty reduces the ability to provide a precise value, and this can determine a non-response or biased value. The literature support that respondents can be uncertain about their preferences (Mahieu et al., 2017; Kahneman & Snell, 1992), and the request to provide a WTP can face several sources of individual uncertainty (Lyssenko & Martínez-Espiñeira, 2012). Empirical studies that analyse contingent valuation data confirm the diffuse uncertainty that people face in providing their precise WTP (Li & Mattsson, 1995; Wang, 1997; Alberini, Boyle, & Welsh, 2003).

When people are asked to state their preferences with a value for marketable or non-marketable goods, the uncertainty in the valuation of the WTP can be increased by the absence of direct experience of the object of the valuation, which may imply the absence of information. In this case, testing the WTP with a design that involves the direct experience circumscribes people's uncertainty only to the individual uncertainty about their valuations. As Ariely et al. (2006) suggest "The benefit of using sounds is that subjects can be given a sample that provides full information about the experience."

Ariely et al. (2006) conducted a series of experiments in which the participants were asked if they were available to pay or to accept a given amount to listen to a poetry reading. They found that in some cases people do not have a pre-existing valuation of an experience. Such that the experience is relevant to provide to the people the information they need to formulate their preference.

These experiments followed the results of Ariely et al. (2003) that showed that valuations of familiar goods and experiences are strongly influenced by the anchoring effect to arbitrary values to which people are exposed. In their experiment, the values to which the participants were exposed were absolutely not related to the object of the valuation and the participants were conscious about that (the number they showed was a person's social security number). But this value has affected the stated preference of the respondents expressed with monetary valuations.

This literature suggests that the presence of biased answers can derive from the uncertainty and the difficulties that individuals face in providing a precise value, and also by the anchoring effect that can be generated by arbitrary values, like the values of closed-ended survey designs and interval estimations with given brackets (Winter, 2003; Comerford, Delaney, & Harmon, 2009; Ariely et al., 2003).

Among the different methodologies for eliciting monetary valuations a closed-ended or open-ended design are adopted (Johnston et al., 2017). Håkansson (2008) explored the classic open-ended questions in which people state their WTP with a single value and either with a range in a survey concerning wild salmon in northern Sweden. Participants did not observe any bid amount to avoid any bias related to the bid design. Håkansson argues that the adoption of open-ended intervals implies some advantages.

The same conclusions are presented by Mahieu et al. (2017), that survey the willingness to pay for the conservation of bears. In their questionnaire, people could state their WTP as a range or as a point. The results show that most people prefer reporting their WTP as a range rather than a point.

Similar results have been obtained by Hanley and Kriström (2002), which explored the idea that people only know the value they place on a given environmental change as a range, rather than as a single point. In a case study about the value of coastal water quality, they elicited the stated preferences adopting the payment ladder design of contingent valuation. They found that most people state their values as a range.

The results of these studies that adopted open-ended intervals to elicit WTP keep with the core aspects of a diffused opinion in the literature which asserts that asking for a range instead that for a unique value responds to the people's preferences to express value using an interval because of the uncertainty they have about their valuation for unfamiliar goods (Hanley et al., 2009; Banerjee & Shogren, 2014; Li & Mattsson, 1995; Ready et al., 1995).

The necessity to address the elicitation methodology to face the uncertainty and the people's preference for providing the WTP with a range rather than a single value, emerges in the valuation literature. As well as the advantage to use experiments that involve sounds. For these reasons, this paper investigates the presence of a dose-response relationship in the context of WTP for an environmental sound improvement and the determinant of the length of self-selected intervals evaluated in realistic sound scenarios.

3. Hypotheses and theoretical setup

Empirical results suggest that individuals are typically uncertain of their precise WTP (Li & Mattsson, 1995; Wang, 1997; Alberini et al., 2003) for public goods such as environmental quality. There are therefore advantages, we argue, to let valuation be represented by a self-selected interval (Håkansson, 2008). In this manner, we can obtain a rudimentary description of the underlying WTP distribution at the individual level (Wang, 1997).

First, we consider if the length of the interval is affected by the level of noise per se. We hypothesize that participants respond with different economic evaluations to different levels of sound. Because the response is interval-valued, responses can overlap and in general display a complex pattern. The sense in which we define a dose-response relationship is detailed below.

We assume that the individual preferences for a given sound level can be defined by a set that includes all the amounts that she will be willing to pay for the given environmental sound improvement. Thus, the individual considers a finite set of intervals and selects the optimal interval, given an implicit ordering on this set.

This setup is similar to that used by Belyaev & Kriström (2015) to define a maximum likelihood estimator that enables the estimation of the distribution function for WTP. In Belyaev & Kriström (2015) WTP is considered to be a point within an interval that the subject finds difficult to report because of uncertainty. Even if "difficult" is a subjective notion, intervals can also appear in a neoclassical context, in which computational complexity and limitations of the human brain play no role. Indeed, as shown by Johansson & Kriström (2020), a WTP-interval can be generated under certainty for a neoclassical consumer.

In the experiment, each respondent offers an interval to describe the subjective valuation of the suggested improvement. This interval defines a set that includes all the amounts the respondent considers reasonable to pay. A descriptive statistic is the average:

$$E[v] = \frac{\sum_{v=min_r}^{max_r} v}{|v|}, \tag{1}$$

where $|V|$ is the cardinality of the set V that includes all the values v in the interval $[min_r, max_r]$.

Uncertainty in the sense used in our context is consistent with the coherent arbitrariness hypothesis. Thus, individuals might arbitrarily select a value inside an interval to represent their preferences, and this selection can be triggered by factors unknown to the individual. We assume that any value within the chosen interval may be selected and considered a true valuation.

We assume continuity in the interval $[min_r, max_r]$ and that the density function of V in the interval $[min_r, max_r]$ -$f(v)$ - is constant such that

$$f(v) = \begin{cases} x, & min_r \leq v \leq max_r \\ 0, & otherwise \end{cases}, \tag{2}$$

then

$$E[v] = \int_{min_r}^{max_r} v{\cdot}f(v)\,dv. \tag{3}$$

Geometrically $E[v]$ corresponds with the middle point of the interval, from (3):

$$E[v] = \left[\frac{1}{2}\cdot\frac{1}{max_r - min_r}\cdot v^2\right]_{min_r}^{max_r} = \frac{max_r + min_r}{2}. \tag{4}$$

For this reason, we use the mid-point of the interval as a descriptive measure.[2]

We define for a given individual the set

$$W_r = \{min_r(s), \ldots, max_r(s)\}, \tag{5}$$

where r is a short for "true", $min_r(s)$ is the minimum valuation for a given sound improvement s, $max_r(s)$ the maximum. In the lab-experiment, the individual reports

$$W_c = \{min_c(s), \ldots, max_c(s)\}, \tag{6}$$

where c is short for "communicated". In the absence of bias

$$min_c(s) = min_r(s) \wedge max_c(s) = max_r(s) \quad \forall s \in S, \tag{7}$$

where S is the set of all environmental sound improvements. $W_c = W_r\ \forall\ s \in S$ is a truth-telling condition.

We assume that the interval bounded by the minimum and maximum amounts is sensitive to the level of the sound improvement, such that:

$$\frac{\partial min_r(s)}{\partial s} \lesseqgtr 0 \wedge \frac{\partial max_r(s)}{\partial s} \lesseqgtr 0 \quad \forall s \in S. \tag{8}$$

We denote L_r as the length of the interval of the true valuation:

$$L_r(s) = max_r(s) - min_r(s). \tag{9}$$

This length may vary with sound levels. $W_c = W_r\ \forall s \in S$ is true when the sensitivity of the reported length L_c is the same as $L_r\ \forall s \in S$. For simplicity, we assume that s is continuous. We define the sensitivity of the length under the no bias condition:

$$\frac{\partial L_r(s)}{\partial s} = \frac{\partial L_c(s)}{\partial s}. \tag{10}$$

During the evaluation task, the respondent constructs the intervals $min_c(s)$ and $max_c(s)$, and these are respectively functions of $min_r(s)$ and $max_r(s)$. If the length communicated by the subject depends only on the midpoint of the interval, then $min_c(s) \simeq min_r(s)$ and $max_c(s) \simeq max_r(s)$, so that

$$L_c(s) = f(max_r(s), min_r(s)). \tag{11}$$

In this case, a change in the sound environment on the length $L_c(s)$ will be

$$\frac{\partial L_c(s)}{\partial s} = \frac{\partial max_r(s)}{\partial s} - \frac{\partial min_r(s)}{\partial s}. \tag{12}$$

If the length of the interval communicated by the subject is affected by the sound level, we define that

$$L_c(s) = f(max_r(s), min_r(s), s), \tag{13}$$

this implies that

$$\frac{\partial L_c(s)}{\partial s} = \frac{\partial max_c(s)}{\partial s} - \frac{\partial min_c(s)}{\partial s} + \frac{\partial L(s)}{\partial s}, \tag{14}$$

where $\frac{\partial L(s)}{\partial s}$ is the direct effect of s on the length of the communicated interval independently of the midpoint.

Let

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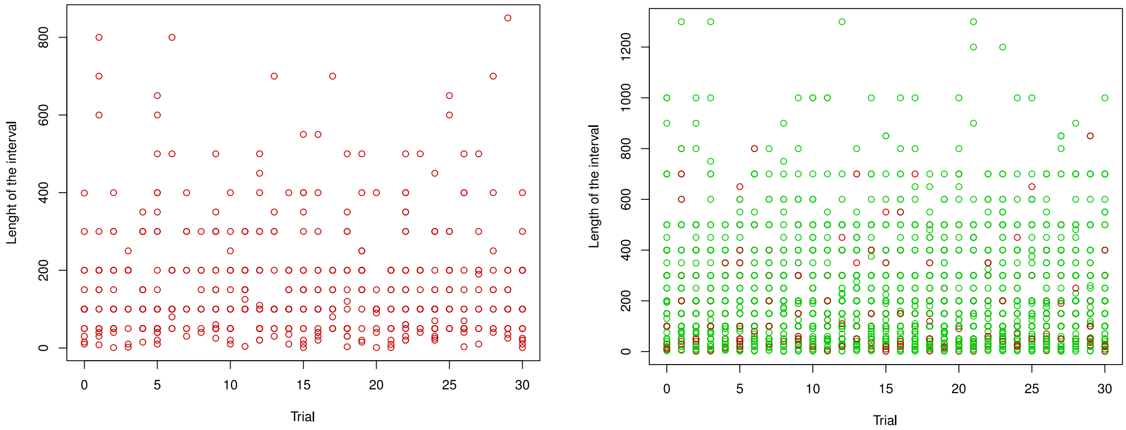
[2] We remark that given an expected value E[v] evaluated as defined in equation 3, the longer the interval that expresses the given expected value, the greater the uncertainty.



(a) Scenarios 1-5

(b) All Scenarios
scenarios 1-5 in red

Fig. 1. Length of the interval over time.

$$\frac{\partial max_c(s)}{\partial s} = \frac{\partial L_c(s)}{\partial max_r(s)} \cdot \frac{\partial max_r(s)}{\partial s} \tag{15}$$

and

$$\frac{\partial min_c(s)}{\partial s} = \frac{\partial L_c(s)}{\partial min_r(s)} \cdot \frac{\partial min_r(s)}{\partial s}. \tag{16}$$

In this case,

$$\frac{\partial L(s)}{\partial s} = \left(1 - \frac{\partial L_c(s)}{\partial max_r(s)}\right) \cdot \frac{\partial max_r(s)}{\partial s} + \left(\frac{\partial L_c}{\partial min_r(s)} - 1\right) \cdot \frac{\partial min_r(s)}{\partial s}. \tag{17}$$

However, independence implies that $\frac{\partial L(s)}{\partial s}$ should be linearly independent of $min_r(s)$ and $max_r(s)$. Observing the right side of the equation (17), it is evident that the condition of independence does not hold when $\frac{\partial L(s)}{\partial s} \lessgtr 0$ for every s in S. If the sound affects the length of the interval, the absence of bias expressed by equation (7) cannot be guaranteed.

In this paper, one goal is to understand the determinants of interval length. We hypothesise that the interval is not independent of the WTP for different sound improvements and is not affected by the sound per se. given the theoretical framework just presented, we formalize these hypotheses as follows:

Hyp.i:

Given $L_c(s)$ defined as in equation (11), $L_r(s)$ defined as in equation (9) ad the relation between $L_c(s)$ and $L_r(s)$ defined as in equation (10). Assuming the sensitivity of $min_r(s)$ and $max_r(s)$ to s defined as in equation (8): then

$$\frac{\partial L_c(s)}{\partial s} = \frac{\partial max_r(s)}{\partial s} - \frac{\partial min_r(s)}{\partial s},$$

and

$$\frac{\partial L_c(s)}{\partial s} \lesseqgtr 0.$$

Hyp.ii: if *hyp.i* is true, given:

$$\frac{\partial L(s)}{\partial s} = \left(1 - \frac{\partial L_c(s)}{\partial max_r(s)}\right) \cdot \frac{\partial max_r(s)}{\partial s} + \left(\frac{\partial L_c}{\partial min_r(s)} - 1\right) \cdot \frac{\partial min_r(s)}{\partial s},$$

then:

$$\frac{\partial L(s)}{\partial s} = 0.$$

These hypotheses are verified empirically in this paper. We now explain the experimental setup.

4. Experimental design

We used a standard psychophysics experiment of changing sound environments. The subjects of the experiment were recruited among university students in Stockholm. Sixty participants participated in the experiment (mean age was 29 years). Each participant received a payment of 200 SEK in total for participating in the experiment, to reward their collaboration and to motivate them.[3] Each participant was requested to report a minimum and maximum amount, that constitute the two endpoints of the interval, in Swedish kronor she considers reasonable to pay per month (compulsory monthly fee) for the residential sound improvement for different scenario pairs, one involving a reduction of noise exposure. The interval that they report is self-selected, and there are no brackets or cues provided.

The participants were seated in a sound laboratory and listened to recordings of outdoor sound environments, recorded in urban Stockholm. The sounds were reproduced, without visual stimuli, in a sound lab with an ambisonic system composed of 25 loudspeakers that create a very realistic sound experience. The participants were asked to imagine that the reproduced sound environment was heard while seated in an outdoor living space in their home. They were requested to define how much they would be willing to pay to reduce the environmental noise from a given sound environment with external noise (typical road noise) to a quiet sound environment. The quiet sound environment had a sound level pressure of 45 dB(A), recorded in a quiet area. Before proceeding with the experiment, the participants did a practice trial.

The key data was obtained by eliciting a WTP-interval for five specific sound scenarios in which the quiet environment was mixed with urban noise, with a specific increasing sound pressure of 5 Bb(A) for each scenario. The noise registrations for the five specific sound scenarios were respectively 40, 45, 50, 55, and 60 dB(A); next, each of these

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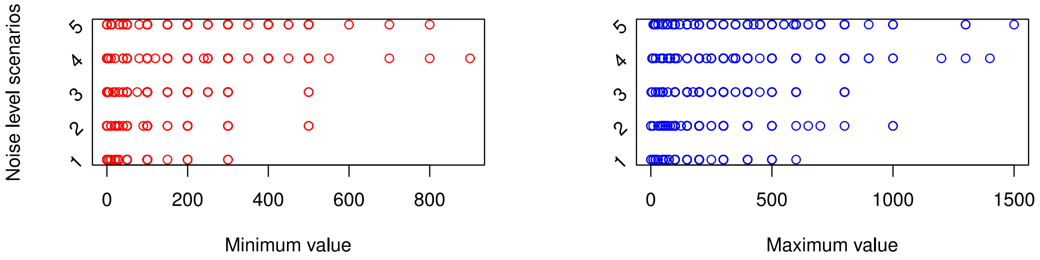
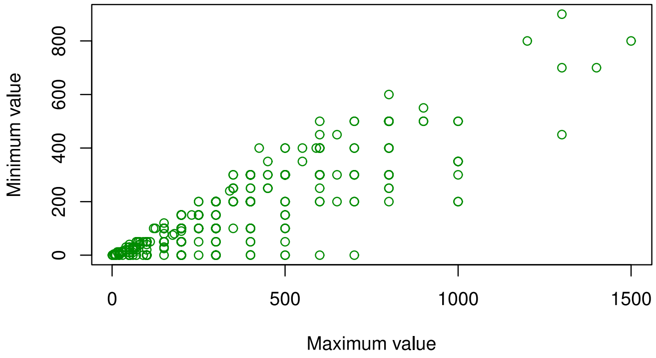
[3] This kind of framework is generally not congenial with the adoption of performance-based incentives (Voslinsky & Azar, 2021). Because the experiment does not involve strategic interaction, but it asks to express preferences in a real-world situation, the participants have no incentive to do not tell the truth about their beliefs (Voslinsky & Azar, 2021). This design does not exclude totally the risk of the hypothetical bias. But it guarantees consistent behavioural patterns to study the dose-response relationship and to investigate the determinants of the length of the intervals. Future researches could explore new designs to investigate the WTP elicitation with a self-selected interval estimate adopting performance-based incentives.



(a) Minimum values for different scenarios (b) Maximum values for different scenarios



(c) Pairs of minimum-maximum values of the intervals

Fig. 2. Relation between the endpoints of the interval and the different noise scenarios.

was mixed with the quiet environment. The different scenarios are denoted 1, 2,...5, from smallest to largest noise reduction. The scenarios were presented to the participant randomly and mixed with 26 scenarios created from selected outdoor recordings. This mixing ensures that the individual does not know which scenario belongs to the specific sound scenarios of the experiment. In each trial, the participant could switch between listening to the quiet sound environment to noisy environments, and vice versa, as many times as the participant thought necessary. The experiment was then repeated with the same respondents and the same scenarios approximately 2 weeks later.

The sample used in the analysis comprised 3439 different interval estimations (516 involved the 5 specific scenarios), with the minimum amount of the interval of the WTP between 0 and 1000 and the maximum between 1 and 1700.[4]

5. Dose-response relationship analysis

First, we verify that there is no correlation between the length of the interval and the repetitions of the task. The plot in Fig. 1 suggests no relationship trend between the length of the intervals and the number of trials.

The absence of correlation (p-value$=0.39$) suggests that participants are consistent in their valuations. Otherwise, we should observe a correlation suggesting a learning effect.[5] The absence of this correlation suggests that individuals usually think in terms of intervals when they must define their valuations. This result is consistent with that of Hanley et al. (2009) who found that individuals prefer reporting their valuations by using an interval rather than a single value.

The absence of a trend over time allows us to investigate whether or not there is a well-defined and systematic time-invariant heuristic, which individuals use when subjected to psychophysics stimuli (the WTP to reduce the noise pressure in absence of visual stimuli is a situation in which this type of stimuli can be an object of economic evaluation).

We proceed by identifying the variables that could explain the length of the interval. We considered mainly the variables that express the preferences of the participants: the minimum and maximum amounts, the noise, and its levels.

We observe a significant correlation between the level of sound and WTP (defined as the midpoint). Both the minimum and the maximum amounts that the participants are willing to pay increase when the sound increases (Fig. 2).[6]

We observe that the mean of the minimum, the mean of the maximum, and the mean of the middle point of the intervals are

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[4] The 60 participants have listened to 31 sound pairs for each of the 2 sections. They provided intervals in 3510 cases. The analysis excludes 71 observations with extremely high values that were greater than the 97.5 percentile (minimum greater than 1000 and maximum greater than 1700). The average values of the sample are respectively for the minimum and the maximum: 137 and 293. Only in the case of one participant, the intervals provided relative to the 5 specific scenarios were extremely high (values around 5000), the intervals of this participant are not included in the 516 interval estimations relative to the 5 specif scenarios analysed.

[5] In the presence of the learning effect, we could expect a smaller interval after the repetition of the same task because the participants gain experience by performing the valuation task, and with the repetitions, they could become more certain about their valuation. The absence of this effect suggests that the task we asked for and the object of the valuation were familiar to the participants.

[6] Correlation with left 0.39 (p-value $<$ 2.2e-16) right 0.37 (p-value $<$ 2.2e-16). Tables 8, 9 and 10 with all the tests for the comparisons among the different scenarios are in the appendix.

Table 1
Average values for different scenarios.

Sound level Scenarios	Mean Minimum	Mean Maximum	Mean middle point intervals
5	219.7739	416.3913	313.0826
4	183.8421	359.8509	271.8465
3	118.8807	264.7982	191.8394
2	85.53684	213.1263	149.3316
1	52.78313	158.3373	105.5602

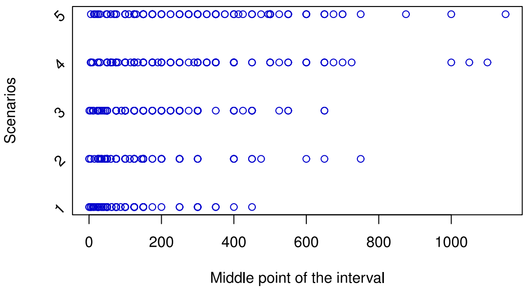


Fig. 3. Middle point of the intervals.

significantly different among the scenarios.[7] The endpoints of the intervals are also strongly correlated (correlation between maximum and minimum, 0.87 – p-value $< 2.2e\text{-}16$), indeed the greater values of the maximum are paired with the greater value of the minimum, as in Fig. 2 (c).

In Table 1 for each scenario, we report the mean of the minimum and the maximum values and the mean of the middle point of the interval. The dose-response is evident and significant. The participants are willing to pay more to benefit from increasing noise reduction in their residential sound environment. This dose-response is identifiable with the use of a self-selected interval, even though the scenario involves hypothetical payments.

We use the midpoint of the interval as one descriptive of WTP. The midpoint of the interval is correlated with the sound level, with a higher WTP in response to higher levels of noise (correlation=0.39, p-value $<$ 2.2e-16; Fig. 3). This correlation does not imply that the level of the sound affects the length of the intervals independently of WTP. We also observe a correlation between the length of the interval and the size of the interval, as measured by the midpoint (correlation=0.75, p-value $<$ 2.2e-16; Fig. 4). In addition, we do not detect significant differences in the mean of the length for different levels of increasing noise (Table 11 in the appendix).

The analysis conducted until this point demonstrates the presence of a dose-response relationship between the level of noise and subjective monetary valuation, measured by using different methods. In Section 6, we present a more detailed investigation of interval length.

6. Independence of the length of the interval from the level of noise

Because we observed a correlation between the sound level and the length of the interval and the midpoint and a correlation between the length and the midpoint, we conduct an econometric analysis to understand this finding in more detail.

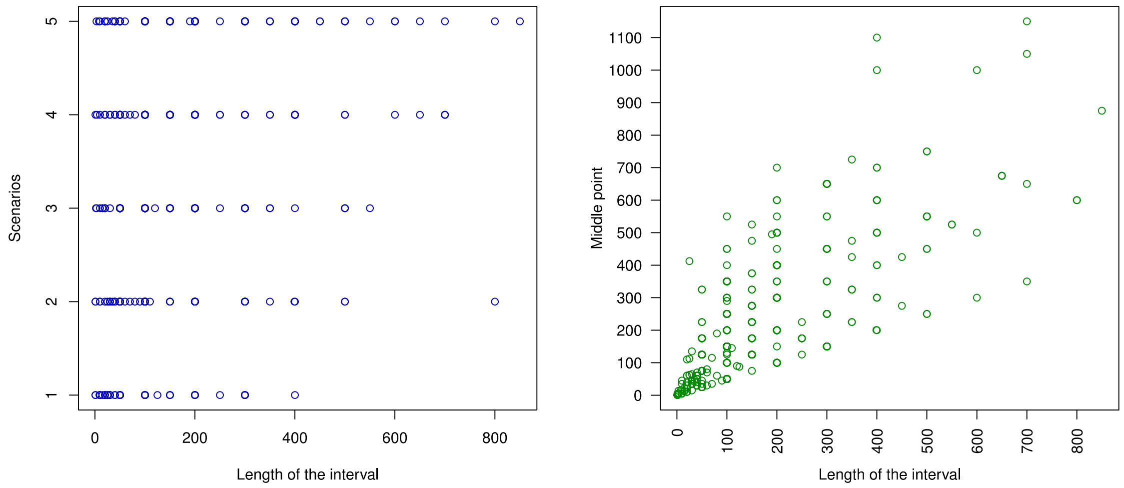
First, we explore the factors that may determine the length of the intervals (LEN) by using polynomial regression. We focus on the midpoint and the sound level. In the first polynomial regression (model 1), we use the midpoint (MID), its square (MIDs), the sound level (SLE), and its square (SLEs). We add an interaction between the middle point and the sound level (MID · SLE):

$$LEN = \beta_0 + \beta_1 MID + \beta_2 MID^2 + \beta_3 SLE + \beta_4 SLE^2 + \beta_5 (MID{\cdot}SLE) + \varepsilon \tag{18}$$

Table 2 reports the results of the polynomial regressions (ordinary least squares) of the model 1 (equation 18) and of the following model 2 (equation 19):

$$LEN = \beta_0 + \beta_1 MID + \beta_2 (MID{\cdot}SLE) + \varepsilon \tag{19}$$

We observe that in model 1 the sound level (SLE) is nonsignificant, as well as its square (SLEs) and the square of the midpoint (MIDs). In the second model, we exclude variables that in model 1 are nonsignificant. As shown in Table 2, in model 2, the midpoint (MID) and the interaction



(a) Length for different scenarios

(b) length and middle point

Fig. 4. Length of the interval in relation to the sound scenarios and the middle points.

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[7] The unique exception is the comparison between scenarios 4 and 5: no difference at 5%. For details, see Tables 8 - 10 in the appendix.

Table 2
Results OLS regressions.

	Dependent variable:	
	LEN	
	Model 1	Model 2
Intercept	49.237**	32.798***
	(21.484)	(6.425)
MID	0.726***	0.693***
	(0.083)	(0.061)
SLE	- 16.254	
	(15.613)	
MIDs	- 0.00001	
	(0.0001)	
SLEs	2.886	
	(2.666)	
MID·SLE	- 0.040*	- 0.033**
	(0.022)	(0.013)
Observations	516	516
R^2	0.570	0.569
Adjusted R^2	0.566	0.567
Residual Std. Error	93.025 (df = 510)	92.863 (df = 513)
F Statistic	135.066*** (df = 5; 510)	338.242*** (df = 2; 513)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 3
ANOVA model 1 vs model 2.

Model 1: LEN ~ MID + SLE + MIDs + SLEs + MID·SLE

Model 2: LEN ~ MID + MID·SLE

Res.	Df	RSS	Df	Sum of Sq	F	Pr(>F)
1	*510*	*4413402*				
2	*513*	*4423864*	*-3*	*-10463*	*0.403*	*0.7509*

Table 4
Splines regression.

	Dependent variable: LEN
Intercept	156.227*** (4.115)
Poly MID 1	2,404.369*** (93.468)
Poly MID 2	- 57.808 (93.468)
Poly MID 3	- 14.270 (93.468)
F Statistic	220.708*** (df = 3; 512)

Note: *p<0.1; **p<0.05; ***p<0.01

between the middle point and the sound level (MID · SLE) are significant. These results offer an indication of the important contribution of the midpoint in the determination of the length of the interval.

The ANOVA test (Table 3) for the two models confirms that the second model has a better explanatory capability. However, the presence of correlation between sound level and middle point that emerged in the previous part of this analysis and the limited capability of prediction of this model (we detected heteroscedasticity and autocorrelation) requires a more detailed analysis.[8]

Before proceeding with the GLS models, we check the relation between the length of the interval and the middle point. We plot the local regression with a smoothing process (Fig. 5). The regression function appears regular. In addition, we run a splines regression using a polynomial of the third order of the variable middle point. As shown in Table 4, among the coefficients of the three independent variables, *MID*, *MID*^{2} and *MID*^{3} (respectively, Poly MID 1, Poly MID 2, Poly MID 3), only the coefficient of the variable of the first order is significant. Jointly these results confirm the regularity of the regression.

The absence of a direct effect of the sound level on the length of the intervals is clarified by comparing the following four different models (results reported in Table 5) by using generalized least squares regressions, autoregressive of order 1, with maximum likelihood estimates, and the exponential variance function weight:

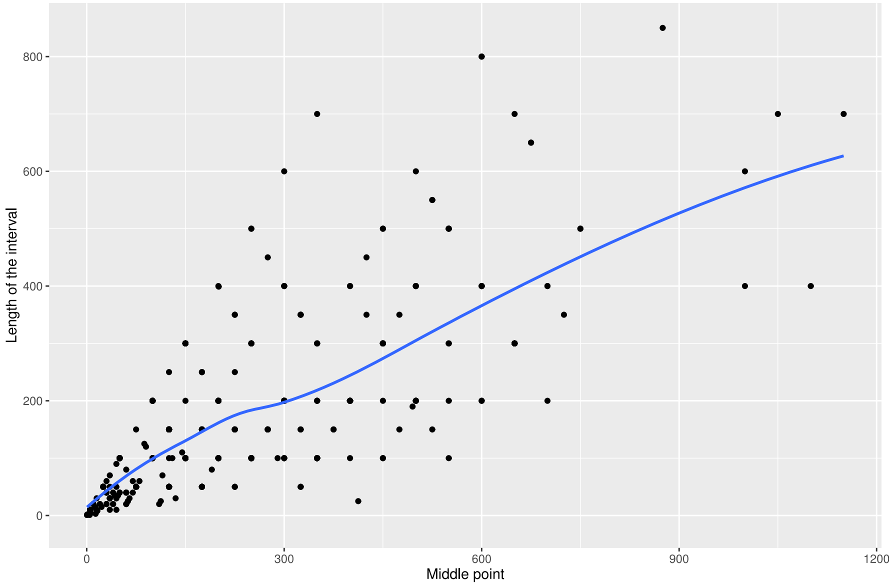

Fig. 5. Plot local regression.

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[8] Heteroscedasticity (Breusch-Pagan p-value = 7.712e-16) and autocorrelation of the residuals (Durbin-Watson test p-value < 2.2e-16).

Table 5
Results GLS regressions.

	Dependent variable:			
	LEN			
	Model 3	Model 4	Model 5	Model 6
Intercept	15.508	16.848^{***}	19.242^{***}	31.608^{***}
	(9.792)	(4.676)	(4.521)	(4.082)
MID	0.912^{***}	0.897^{***}	0.807^{***}	0.596^{***}
	(0.079)	(0.072)	(0.053)	(0.029)
SLE	0.030			
	(7.283)			
MIDs	$-\ 0.0004^{***}$	$-\ 0.0004^{***}$	$-\ 0.0004^{***}$	
	(0.0001)	(0.0001)	(0.0001)	
SLEs	0.189			
	(1.260)			
MID·SLE	- 0.034	$-\ 0.026^{*}$		
	(0.022)	(0.014)		
Observations	516	516	516	516
Log Likelihood	- 2,866.144	- 2,865.523	- 2,865.347	- 2,965.771
Akaike Inf. Crit.	5,750.289	5,745.047	5,742.693	5,939.541
Bayesian Inf. Crit.	5,788.504	5,774.770	5,768.170	5,956.526

Note: *p<0.1; **p<0.05; ***p<0.01

Table 6
ANOVA GLS models.

Model	*AIC*	*BIC*	*logLik*	*Test*	*L.Ratio*	*p-value*
3	5750.289	5788.504	-2866.144			
4	5745.047	5774.770	-2865.523	3 vs 4	1.24200	*0.5374*
5	5742.693	5768.170	-2865.347	4 vs 5	0.35353	*0.5521*
6	5939.541	5956.526	-2965.771	5 vs 6	200.84796	*<.0001*

MODEL 3.

$$LEN = \widehat{\beta}_0 + \widehat{\beta}_1 MID + \widehat{\beta}_2 MID^2 + \widehat{\beta}_3 SLE + \widehat{\beta}_4 SLE^2 + \widehat{\beta}_5 (MID \cdot SLE) + \varepsilon \tag{20}$$

MODEL 4.

Table 7
Regression with dummies.

	Dependent variable: LEN
Intercept	19.835^{***} (5.047)
MID	0.827^{***} (0.056)
MIDs	$-\ 0.0005^{***}$ (0.0001)
D2	0.697 (4.958)
D3	- 4.478 (6.018)
D4	- 4.128 (6.587)
D5	- 7.269 (6.445)
Observations	516
Log Likelihood	- 2,863.851
Akaike Inf. Crit.	5,747.701
Bayesian Inf. Crit.	5,790.162

Note: *p<0.1; **p<0.05; ***p<0.01

$$LEN = \widehat{\beta}_0 + \widehat{\beta}_1 MID + \widehat{\beta}_2 MID^2 + \widehat{\beta}_3 (MID \cdot SLE) + \varepsilon \tag{21}$$

MODEL 5.

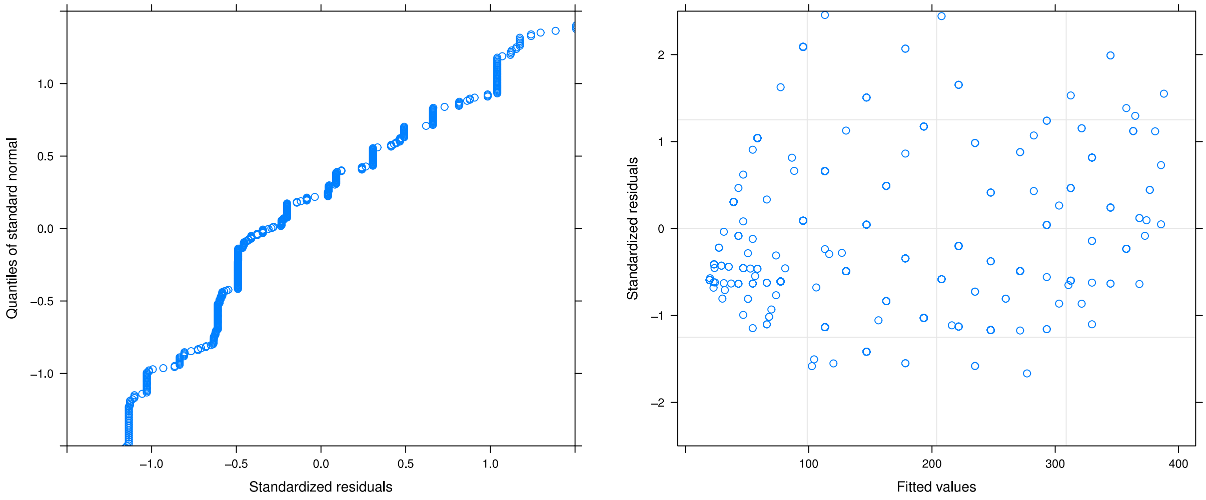
$$LEN = \widehat{\beta}_0 + \widehat{\beta}_1 MID + \widehat{\beta}_2 MID^2 + \varepsilon \tag{22}$$

MODEL 6.

$$LEN = \widehat{\beta}_0 + \widehat{\beta}_1 MID + \varepsilon \tag{23}$$

The analysis shows that the only variable of significance is the middle point (this is true in all the models). The ANOVA test (Table 6) demonstrates that model 5 shows the best fit. This model also includes the square of the middle point. However, the value of the coefficient is small (-0.00044). The t-test on the residuals of model 5 suggests that the assumptions are supported (p-value = 0.9778). A graphic analysis of residuals of this model is in Fig. 6. The good explanatory capability of the model is confirmed by a pseudo R squared of 0.734.[9]

We next introduce dummy variables for the sound level. The introduction of the dummies confirms that the sound does not affect the length of the interval per se. Table 7 reports the results of the regression of the model with dummies. The results are confirmed by the linear hypothesis test on the regression coefficients (Pr(>Chisq)=0.67).[10]



(a) Q-Q plot (b) Residuals vs fitted

Fig. 6. Residuals GLS regression model 5.

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[9] Cox and Snell (ML)=0.734124. Cragg and Uhler=0.734126.

[10] The performed test is reported in the appendix (Table 12).

7. Conclusion

Standard elicitation approaches used to obtain quantitative information typically assume that individuals can provide a precise value. For unfamiliar (as well as familiar) goods, this is a strong assumption. We suggest the use of self-selected intervals, in which the shortest possible interval is a point, i.e. the standard case.

To explore this idea we use a state-of-the-art psychophysics lab experiment (N=60), in which five specific sound environments were randomly inserted into a set of 31 pairwise comparisons to elicit the subjective value of reducing ambient noise; each respondent experienced a different sequence of pairings and reported their subjective valuation (in monetary terms). We collect this valuation as a self-selected interval, allowing for respondent uncertainty. In contrast to the typical contingent valuation experiment, there is no uncertainty about the project under consideration. Because respondents invariably reported an interval rather than a point (i.e., the shortest possible interval), there is individual valuation uncertainty.

We found that valuation uncertainty, measured as the length of a self-selected interval, is independent of the psychophysical conditions. The length of the interval is determined mainly by the subjective value of improving the environment, independent of the level of noise. These results, according to our review of the literature, are new.

We conducted this study to investigate the presence of a dose-response relationship in the interval context and to understand the main determinant of the length of the interval. We hypothesised that the interval including the willingness to pay for an environmental sound improvement in the residential urban environment reflects the presence of a dose-response relationship with the level of noise to which individuals are exposed. We hypothesised also that, in presence of a dose-response relationship, the length of the interval is independent of the level of noise per se. The analysis showed that both our hypotheses are positively verified.

As discussed in the literature review, the adoption of self-selected interval estimations for the WTP responds to the diffused opinion and the evidence that people are uncertain about their precise WTP and they prefer to express their preferences with a range rather than a single value. The adoption of self-selected intervals in the stated preferences elicitation can reduce the response errors and the bias derived by the uncertainty.

The hypotheses we verified are relevant for the adoption of this architecture in the contingent valuation.

Indeed with the first hypothesis, we demonstrate that by asking for a self-selected interval we can capture the relation between the individual preferences expressed in monetary terms and the object of the preferences. In the case of this experiment, the relation between the WTP for an environmental sound improvement and the reduction of noise.

The second hypothesis was relevant because the condition of independence of the length of the interval by the sound level per se is necessary to assume the truth-telling condition. Indeed, the interval communicated by the respondents to be considered representative of people's preference, requires that the communicated WTP derive only from their belief about the WTP. If the interval was affected by the level of sound per se this requirement would be violated.

Our hypotheses have been verified. The interval captures the existence of a dose-response relationship. The length of the interval depends only on the values that represent the preferences of the participants, without being affected by the level of sound per se. Such that the length of the intervals is a truthful expression of the willingness to pay that they manifest in response to the level of noise.

This represents an advancement in the investigation about the advantages to adopt self-selected intervals in the elicitation of stated preference for the valuation of non-market goods and services, such as environmental improvement and preservation. These results qualify this instrument as a promising method in the toolbox of environmental valuation.

Our results suggest that self-select intervals used to elicit preferences is a promising method for further research, not the least in the valuation literature. The adoption of self-selected intervals offers the opportunity to continue to study the economic and monetary responses to environmental sound stimuli. Among potential further studies, there is the possibility to adopt self-selecting intervals to compare different behavioural patterns that can emerge in front of different sources and types of sounds both familiar and unfamiliar for the participant. Interval elicitation enables individuals to provide reasonably consistent rankings of environmental improvements, even if individuals find it difficult to pin down a precise value. Thus, self-selected interval elicitation seems to have merit.

Appendix A

Table 8
T-test p-values difference in mean of the minimum of the intervals for different scenarios.

SCENARIO	[1]	[2]	[3]	[4]	[5]
[1]	1,00E+06	1,29E+04	4,36E-01	1,20E-05	6,11E-10
[2]	1,29E+04	1,00E+06	2,49E+04	1,03E+00	5,78E-04
[3]	4,36E-01	2,49E+04	1,00E+06	8,66E+02	2,59E+00
[4]	1,20E-05	1,03E+00	8,66E+02	1,00E+06	2,53E+05
[5]	6,11E-10	5,78E-04	2,59E+00	2,53E+05	1,00E+06

Table 9
T-test p-values difference in mean of the maximum of the intervals for different scenarios.

SCENARIO	[1]	[2]	[3]	[4]	[5]
[1]	1,00E+06	3,05E+04	1,07E+01	3,50E-04	1,41E-08
[2]	3,05E+04	1,00E+06	5,96E+04	1,66E+01	7,00E-03
[3]	1,07E+01	5,96E+04	1,00E+06	3,41E+03	5,46E+00
[4]	3,50E-04	1,66E+01	3,41E+03	1,00E+06	1,34E+05
[5]	1,41E-08	7,00E-03	5,46E+00	1,34E+05	1,00E+06

Table 10
T-test p-values difference in mean of the middle point of the intervals for different scenarios.

SCENARIO	[1]	[2]	[3]	[4]	[5]
[1]	1,00E+06	1,76E+04	1,49E+00	2,69E-05	4,90E-10
[2]	1,76E+04	1,00E+06	3,69E+04	3,01E+00	7,31E-04
[3]	1,49E+00	3,69E+04	1,00E+06	1,50E+03	1,84E+00
[4]	2,69E-05	3,01E+00	1,50E+03	1,00E+06	1,58E+05
[5]	4,90E-10	7,31E-04	1,84E+00	1,58E+05	1,00E+06

Table 11
T-test p-values difference in mean of the length of the interval for different scenarios.

SCENARIO	[1]	[2]	[3]	[4]	[5]
[1]	1,00E+06	1,80E-01	7,24E-03	8,41E+01	2,85E-01
[2]	1,80E+05	1,00E+10	2,80E-01	1,29E+04	1,67E+02
[3]	7,24E+03	2,80E-01	1,00E+09	9,68E+04	2,05E+03
[4]	8,41E+01	1,29E-02	9,68E-02	1,00E+06	1,57E+05
[5]	2,85E-01	1,67E-04	2,05E-03	1,57E+05	1,00E+06

Table 12
Linear hypothesis.

	Hypothesis:	
	MID:d_2 - MID:d_3 = 0	d_2: MIDs - d_3: MIDs = 0
	MID:d_2 - MID:d_4 = 0	d_2: MIDs - d_4: MIDs = 0
	MID:d_2 - MID:d_5 = 0	d_2: MIDs - d_5: MIDs = 0
Model 1:	Restricted model	
Model 2:	LEN ∼MID + MID x d_28 + MID x d_29 + MID x d_4 + MID x d_5 + MIDs + MIDs x d_2 + MIDs x d_3 + MIDs x d_4 + MIDs x d_5	
	Chisq	**Pr(>Chisq)**
1 vs 2	4.0766	0.6663

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