Willingness-to-pay for Noise Abatement in Singapore

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Declaration

The contents of this thesis are original work by the PhD candidate. To the best of the candidate’s knowledge, it contains no material written by another person or institution, except as acknowledged. This thesis has not been submitted for a degree at any other university or institute of tertiary education.

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Abstract

Noise in urban centres adversely affects the health of residents and the liveability of the city. To inform the formulation of noise control policies, the marginal benefits of publicly-provided noise abatement are examined in this thesis. The studies in this thesis were conducted in Singapore, a dense urban centre with elevated levels of noise. Marginal benefits of reducing noise from construction activity and roads were estimated as these are key contributors to noise pollution in Singapore.

Stated preference surveys have been used to estimate the marginal benefits of noise abatement. The veracity of estimates obtained from these surveys depends on respondents' understanding of the information provided in the survey questionnaire. Since noise is measured in decibels, which is scaled logarithmically, respondents may not understand changes to the noise levels when described in physical units. In response to the challenge of communicating different noise levels to respondents, a wide range of textual descriptions has been developed and utilised. However, all these text-based descriptions require respondents to read, understand, and interpret the descriptions. Respondents' interpretation of these textual descriptions may be subjective, leading to inaccurate estimates of their willingness-to-pay for noise abatement.

The surveys conducted in this thesis seek to overcome the challenges of describing construction and road noise textually with an innovative approach of describing changes to noise levels with actual audio recordings. Use of noise recordings enabled survey respondents to hear the change in noise levels without having to subjectively interpret descriptions of noise, hence removing the ambiguity of text-based descriptions.

To test the effect of audio- and text-based representations on willingness-to-pay for noise abatement, a text-based survey was designed. With the exception of the description of noise, the valuation questions in both survey questionnaires are the same, enabling the isolation of the effect of noise representation on willingness-to-pay. Respondents to the text-based survey were found to have a lower willingness-to-pay on average. Further analysis suggests that this difference was due to a lack of understanding of the information in the survey questionnaire. This result suggests that previous text-based questionnaires may have underestimated the willingness-to-pay for noise abatement.

Finally, three sources of heterogeneity were examined, namely prior private spending on noise abatement measures, hearing sensitivity, and distance between noise sources and receptors. These sources of heterogeneity were found to influence the willingness-to-pay for

noise abatement, suggesting that cost-benefit analysis of publicly-provided noise abatement should take into account these factors when estimating the marginal benefits of noise abatement.

The estimated marginal benefits can inform cost-benefit analysis of noise abatement policies. In the absence of government policies, market failures cause noise emissions to be higher than optimal. However, without rigorous cost-benefit analysis, governments may under- or over-provide noise abatement and these policies may not improve the welfare of society. Hence, cost-benefit analysis can inform the design of noise abatement policies and ensure that policy-makers know whether a policy results in a potential Pareto improvement.

List of Abbreviations

AIC	Akaike Information Criterion
ASC	Alternative specific constant
AU$	Australian dollars
BCA	Building and Construction Authority, Singapore
BIC	Bayesian Information Criterion
dB	Decibel
€	Euros
HDB	Housing Development Board, Singapore
Hz	Hertz
IID	Independently and identically distributed
kHz	Kilohertz
km	Kilometres
LTA	Land Transport Authority, Singapore
m	Metres
MB	Marginal benefits
MC	Marginal costs
min	Minutes
MEWR	Ministry of the Environment and Water Resources, Singapore
MOT	Ministry of Transport, Singapore
MRC	Media Research Consultants
MRT	Mass Rapid Transit
NEA	National Environment Agency, Singapore
NSDI	Noise sensitivity depreciation index

Pa	Pascal
QCF	Quieter Construction Fund
QCIF	Quieter Construction Innovation Fund
S$	Singapore dollars
URA	Urban Redevelopment Authority, Singapore
US$	American dollars
W	Watts

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Chapter 1: Introduction

1.1 Control of urban noise pollution

Noise is a key factor affecting the liveability of a city (Jakovljevic, Paunovic & Belojevic 2009; Zannin et al. 2003). The levels of noise in urbanised cities can adversely affect the mental and physical health of residents of these cities. Symptoms of these adverse health effects range from sleep disturbance and annoyance at one end of the spectrum to hearing impairment, hypertension, and ischemic heart disease at the other extreme (Basner et al. 2014; Ising & Kruppa 2004; Stansfeld & Matheson 2003). As a result of increasing numbers of people living in urban areas and the increased loudness and prevalence of noise within cities, Raimbault and Dubois (2005) found that noise pollution has affected an increasing proportion of the world population since the 1970s.

Excessive noise pollution arises due to market failure. In an ideal situation, where a market for noise abatement exists and is competitive, private property rights are assigned and are defensible, and all agents have perfect information and are maximisers, a free market yields an efficient level of noise abatement (Perman et al. 2003). At the efficient level of noise abatement, it is not possible to improve the welfare of an individual without worsening the well-being of at least one other person. In reality, abatement of noise pollution violates these conditions on several accounts. First, the market for noise abatement does not exist. Second, property rights to a quiet environment are not well defined as the provision of noise abatement is non-excludable and non-rivalrous. Consequently, noise sources (e.g., construction companies and vehicle drivers) cause harm to noise receptors (i.e., residents living near noise sources) and do not compensate noise receptors for the disamenities arising from noise pollution.[1] As a result, noise sources produce higher than optimal levels of noise pollution since the damage to noise receptors are not internalised by the noise source.

There are several responses to noise pollution. First, private provision of noise abatement within the homes of residents can reduce the adverse effects of noise pollution.

[1] The direction of compensation depend on the allocation of property rights. If receptors have the right to a quiet environment, they are compensated for the damages caused by noise sources. If sources have the right to emit noise, receptors compensate sources so that sources will reduce their noise emissions.

Unlike some global pollutants (such as the emissions of chlorofluorocarbons), noise pollution is a local pollutant and residents may have recourse to privately provide noise abatement. An example of privately-provided noise abatement is the installation of double-glazed windows to reduce noise in the homes of residents. However, private provision of noise abatement may not be cost-effective as noise abatement that can potentially be provided publicly at lower costs (Gilchrist & Allouche 2005). In addition, the scope of privately-provided noise abatement is limited as noise abatement in residents' home do not reduce outdoor noise. Hence, privately-provided noise abatement may not reduce noise pollution efficiently as costs of private measures are higher and their benefits are more limited as compared to publicly-provided measures.

A second method to correct market failure is the allocation of defensible property rights that enables noise sources and receptors to negotiate a mutually agreeable level of noise abatement. Coase Theorem states that if property rights are defined, trade is possible, and transaction costs are sufficiently low, bargaining can lead to the efficient level of noise abatement (Coase 1960). However, in practice, these conditions are unlikely to be completely fulfilled due to several factors. First, in some jurisdictions, rights to a quiet environment are not well-defined (Block 2003; Friedman 2003). Second, no mechanism currently exists for noise receptors and noise sources to trade. Third, transaction costs will likely be high. Costs of monitoring and enforcement of noise levels are high, given the costs of purchasing and maintenance of monitoring equipment. Further, there may be a large number of noise receptors and sources, increasing transaction costs. The difficulty with assigning and defending property rights as well as the frictions to trade indicate that Coasian bargaining is unlikely to result in an efficient level of noise abatement.

The third method to correct market failure involves government intervention. Given the inefficiencies with private-provision of noise abatement and the infeasibility of Coasian bargaining to reduce noise levels, governments have enacted policies to correct the market failure from noise pollution (Foo 1996; Gilchrist & Allouche 2005). The government can intervene in two ways. First, it can impose market-based mechanisms such as charges or fees on noise pollution. Second, it can mandate command-and-control policies, such as imposing a maximum noise level or mandating specific noise control measures. These noise control measures can be further categorised into (i) zoning, (ii) noise management at source, and (iii) mitigation along the sound path (Sáenz & Stephens 1986).

Zoning involves the physical separation of residents and noise generating activity, which reduces the effects of the noise on residents (Murphy & King 2011). This form of noise regulation can be used to control industrial noise and certain types of transportation noise. For example, industrial zones can be located away from residential areas, with more heavily polluting industries located further away as compared to light industries. Similarly, noise from airports and seaports can also be controlled through appropriate zoning (Revoredo & Slama 2008). Zoning can reduce noise from airports and seaports by siting airports and seaports away from residential areas. The planning of air routes so that aeroplanes do not overfly residential areas can also reduce the effect of aircraft noise on residents. Studies on noise propagation can be used to inform urban planning strategies to reduce the impact of noise pollution of industrial activities on residents (Xie, Liu & Chen 2011).

Source management of noise involves the reduction of noise produced at the source. For instance, construction noise could be reduced by using quieter construction equipment, which emits less noise. This form of control may be effective if machinery can be replaced with quieter alternatives or if the machinery can be used less often.

Path mitigation of noise seeks to absorb noise as it travels from the source to the receptor. An example of path mitigation is the erection of noise barriers along roads. Path mitigation can be employed in tandem with source control in order to provide a further reduction in noise levels.

These policies enacted by the government are collectively termed publicly-provided noise abatement. For ease of exposition, in the remainder of the thesis, noise abatement measures refer to publicly-provided measures, unless otherwise specified.

When noise abatement is privately-provided, each resident decides whether to invest in noise abatement measures based on their private valuation of the benefits provided by these measures. Similarly, if property rights can be assigned and Coasian bargaining occurs, noise sources and receptors can negotiate based their private valuation of the costs and benefits of noise abatement. By comparison, the effects of a change in publicly-provided noise abatement on society are not known *ex ante* as the policy-maker does not have prior information on the marginal benefits and marginal costs functions of noise abatement.

Without information about the costs and benefits of noise abatement, noise abatement policies enacted by the government may not improve the welfare of society. For example, Rosenberg (2016) found that lobby groups have formed advocating for the reduction of noise.

These lobby groups label noise-making as being morally inappropriate and uncivilised. They seek to reduce noise by lobbying for increased noise regulations. Industry lobby groups may also petition the government to relax noise abatement measures. For example, the Office of Noise Abatement and Control in the United States was defunded as a result of industry lobbying efforts (Fink 2016). The rent-seeking behaviour by noise receptors and sources may result in regulations that do not improve society's welfare. Consequently, to prevent government failures, cost-benefit analysis can be conducted to estimate the welfare change attributable to a change in noise abatement policy. The cost-benefit framework is discussed in the next section.

1.2 Estimating welfare changes from public provision of noise abatement

Cost-benefit analysis is a framework that can be used to evaluate changes to environmental policies. In a cost-benefit analysis, the potential welfare changes to society are estimated by comparing the monetary value of benefits and costs associated with a change in environmental policy (Perman et al. 2003). Different criteria can be used to determine whether a particular policy change should be implemented. A criterion that can be used is the concept of Pareto improvement. A change in environmental policy results in a Pareto improvement if at least one individual achieves increased benefits while no other individual is made worse-off. Such a policy should be implemented as the welfare of society is improved. Nonetheless, the definition of a Pareto improvement is restrictive, since most policies result in at least one individual becoming worse-off. In theory, if a policy results in increased net benefits, a Pareto improvement can be achieved by reallocation, i.e., gainers from the policy change compensate losers. However, in practice, the reallocation of net benefits is challenging to implement. The Kaldor-Hicks criterion relaxes restrictions of a Pareto improvement by separating efficiency from equity (Kolstad 2000). The Kaldor-Hick criterion states that a policy that generates net benefits for society should be implemented even if no compensation payments are made. This relaxation of the Pareto improvement is also termed potential Pareto improvement.

Specific to noise abatement, potential benefits of noise abatement accrue to residents due to lower levels of noise abatement and potential costs are borne by noise sources to reduce their noise emissions. To illustrate the benefits and costs of publicly-provided noise abatement, suppose there are $i \in I$ residents and $j \in J$ noise sources. Suppose that the government is evaluating a policy, k, which seeks to implement $\widehat{\alpha_{jk}}$ level of noise abatement.

First, consider the marginal benefits of noise abatement[2]:

$$MB_i\left(\sigma\left(\varphi(\widehat{\alpha_{jk}})\right)\right), \forall j \tag{1-1}$$

where $MB_i(\cdot)$ refers to the marginal benefit of policy k. S_i is the characteristics of the individual and z_{ik} represents the characteristics of policy k other than noise abatement. Implementing noise abatement measures changes the baseline level of noise from each noise source, which is transferred to resident i's location. The perceived level of noise due to noise source j is $\varphi(\widehat{\alpha_{jk}})$ and the total level of noise is $\sigma\left(\varphi(\widehat{\alpha_{jk}})\right)$. $\varphi(\cdot)$ and $\sigma(\cdot)$ are the noise transfer and noise aggregation functions respectively.

Next, consider the marginal costs of noise abatement.[3] The costs of providing $\widehat{\alpha_{jk}}$ is given by a cost schedule, $MC_j(\widehat{\alpha_{jk}})$ that maps $\widehat{\alpha_{jk}}$ level of abatement to the costs of providing this level of abatement.

The welfare change arising from the policy to provide $\widehat{\alpha_{jk}}$ level of noise abatement is the difference between the marginal benefits and marginal costs functions, aggregated across all I residents and J noise sources. In other words, the net benefits function is given by:

$$NB = \sum_i^I MB_i\left(\sigma\left(\varphi(\alpha_{jk})\right)\right) - \sum_j^J MC_j(\widehat{\alpha_{jk}}) \tag{1-2}$$

A potential Pareto improvement results if the aggregate marginal benefits of the policy are higher than the aggregate marginal costs of implementing the noise abatement. In other words, a noise abatement policy should be implemented if the net benefits of the policy, as described by Equation (1-2) is greater than zero.

To estimate the welfare change associated with a proposed noise abatement policy, it is necessary to have information on the noise transfer and noise aggregation functions, which are arguments of the marginal benefits function. These functions have been studied in the acoustic engineering literature.[4] Information on the marginal benefits and marginal costs functions are also required. The marginal benefits of noise abatement depend on the preferences of residents and the marginal costs depend on the market costs of noise abatement

[2] For a detailed derivation of the marginal benefits function, see Section 2.2.2.
[3] Further discussion on the marginal costs function is provided in Section 2.2.3.
[4] See Section 2.5 for a discussion on the physical characteristics of noise.

measures. Information on the marginal costs and marginal benefits functions can be obtained from the economics literature.

Marginal costs imposed by increased noise control can be approximated with the market costs of implementing these abatement measures. Costs of source control are typically associated with the costs of replacement of equipment. For example, construction companies can be required to purchase quieter construction equipment to reduce noise emissions. Quieter pieces of equipment may be costlier than noisier equipment that serve the same function. Similarly, source control of road noise may involve regulations mandating retrofitting of vehicles with mufflers, which cause vehicle owners to incur additional costs. Costs of path control typically involve the erection of noise barriers between the noise source and residences, which incurs costs associated with the purchase, building, and maintenance of the barriers. Other path mitigation measures, such as buffer spaces between noise sources and residences, incur opportunity costs in land-scarce cities.

Unlike the marginal costs function, the marginal benefits function cannot be obtained from market prices as no market for noise abatement exists. Non-market valuation techniques have been developed to estimate the value of such non-marketed goods. These non-market valuation techniques can be broadly classified into revealed preference methods, including hedonic pricing and travel costs methods, and stated preference methods, including contingent valuation and choice modelling.

The revealed preference method estimates an implicit price function from price changes in a proxy market. Estimating the marginal benefits of a policy change requires a second-stage regression using demographic details of residents as exogenous shift variables since the implicit price function is jointly determined by the demand and the supply in the proxy market (Rosen 1974). However, this second stage regression is not carried out in most previous revealed preference studies as researchers do not have access to the demographic details of residents (Parmeter & Pope 2013).

In comparison to revealed preference studies, stated preference studies infer the values of policy changes based on responses to surveys. These studies construct hypothetical scenarios and ask respondents to state their preferred scenario. In order for stated preference studies to elicit responses that accurately reflect the true preferences of respondents, the survey questionnaire should describe the baseline and alternative scenarios using clear and understandable language (Johnston et al. 2017). Stated preference surveys can be broadly categorised into the contingent valuation studies and choice modelling studies. Contingent valuation studies aim to elicit the valuation of an environmental good by presenting respondents with a hypothetical change in the environment and asking individuals if they are willing to pay for that change. Choice modelling studies extend contingent valuation studies by presenting respondents with a series of choice situations, each designed with a fixed set of attributes but with varying levels in each attribute. Analysis of responses to a choice modelling survey provides an estimate of the willingness-to-pay for each attribute.

Previous stated preference studies on noise abatement have mainly relied on a textual description of noise (see, for example, Navrud (2002)). However, unlike some other environmental goods, text-based description of different noise levels is challenging as noise is measured in decibels, which is not readily understandable by most respondents. Other printed representation of noise, such as pictures and symbols, cannot accurately convey different noise levels. Consequently, a wide range of textual descriptions has been used to illustrate changes to noise levels in previous studies. Studies have attempted to describe changes in noise levels with a percentage or level change (Garrod, Scarpa & Willis 2002; Pommerehne 1988; Sælensminde 1999; Sælensminde & Hammer 1994; Soguel 1996; Wardman & Bristow 2004) or with a change in the level of annoyance (Galilea & Ortúzar 2005; Huh & Shin 2018; Kim et al. 2019; Lambert & Champelovier 2001; Li et al. 2009; Navrud 2000). Studies have also used changes to contexts to describe different noise levels, such as differences in noise levels at different times of the day (Barreiro, Sánchez & Viladrich-Grau 2005), variation in the volume of traffic (Vainio 2001), and different apartment locations (Arsenio, Bristow & Wardman 2006).

Use of textual descriptions to communicate changes to noise levels is challenging. Respondents to text-based surveys are asked to read and interpret changes to noise levels. Since the interpretation is subjective, the analyst is unable to observe the noise level that respondents have in mind when answering the survey questionnaire. Further, even if respondents understand the textual description, Galilea & Ortúzar (2005) found that respondents' memory of noise levels was inaccurate and respondents' recalled loudness did not correlate with physical measures of noise levels. As a result, different textual representations can also lead to large variations in estimated willingness-to-pay. For example, Kaushali, Toner & Chen (2018) found changes to apartment locations resulted in an estimated willingness-to-pay of €0.87 per month for a unit improvement in the perceived loudness of the noise. If respondents were asked whether they were willing to pay to reduce noise from 'noisy' to 'quiet', the estimated willingness-to-pay was €74.8 per month. These results suggest that text-based stated preference surveys may have inaccurately estimated the marginal benefits of noise abatement.

1.3 Research motivation

Given the challenges associated with private provision of noise abatement and Coasian bargaining, the research conducted in this thesis focuses on the design of government noise abatement policies that can result in a potential Pareto improvement. Since residents in urbanised cities are more adversely affected by noise as compared to rural residents, urban noise abatement policy is examined. Singapore is used as a case study in the studies conducted in this thesis. A high population density and elevated noise levels have exposed Singapore residents to elevated levels of noise pollution.[5]

Public provision of noise reduction from two noise sources are examined, namely noise from construction activity and road noise. Control of noise from these sources is challenging as it is not practicable to separate residential areas from construction activity and roads. The development of amenities in residential areas makes it inevitable that some residents would be affected by construction noise. Further, roads provide connectivity between residences and other areas in the city, requiring some roads to be built near residential areas. Hence, construction and road noise cause more annoyance for residents as compared to other sources, such as industrial noise and noise from airports.

The information required to conduct a cost-benefit analysis of changes to noise abatement policy are the marginal benefits and marginal costs functions of noise abatement as well as the physical characteristics of noise. With the exception of marginal benefits of noise abatement, the other components of the cost-benefit analysis can be estimated from existing sources. Specifically, the physical characteristics of noise have been examined in the acoustic engineering literature and the marginal costs of noise abatement can be estimated by observing the market prices of abatement measures.

By comparison, the marginal benefits function is estimated with non-market valuation techniques. The lack of detailed administrative data on the individual demography of respondents precludes the use of a revealed preference approach since the second-stage regression cannot be estimated. Previous stated preference studies estimating the willingness-

[5] With a total population of 5.6 million living on an island slightly larger than 700km^2 (Statistics Singapore 2018d), Singapore has the second highest population density in the world. The entirety of Singapore is urbanised and none of its population live in rural areas (CIA 2018). See Section 2.1 for a discussion on Singapore's noise pollution.

to-pay for noise abatement used textual descriptions of noise. Textual descriptions require respondents to understand the description and interpret the changes in described noise levels.

The challenge of preparing a textual description of noise levels that is readily understandable motivates the design of a novel survey questionnaire that describes changes to noise levels with audio recordings. Two choice modelling surveys were conducted with the audio-based survey questionnaire design to estimate the marginal benefits of public provision of construction and road noise abatement. Use of a choice modelling survey enables the estimation of preference for different attributes. Given the novel design of the survey questionnaires, both surveys were conducted across several phases.[6] Specifically, the construction noise survey comprised of focus group discussions to refine the survey questionnaire, followed by a laboratory survey to further refine and troubleshoot the questionnaire in a controlled environment, and a door-to-door field survey that provides the data for the key research findings. The road noise survey comprised of focus group discussions followed by the door-to-door survey.

The audio-based surveys conducted in this thesis used an innovative questionnaire design that has not been previously used in stated preference studies estimating the value of noise abatement. These surveys are the first to enable respondents to hear the loudness of different noise levels. Unlike previous stated preference surveys estimating the marginal benefits of noise abatement, respondents to the audio-based survey do not need to understand and interpret textual descriptions of noise levels. Further, the analyst has full information on the respondents' interpretation of each noise level in the questionnaire, enabling an accurate estimate of respondents' preferences for noise abatement measured on the decibel scale. Since noise policies are based on physical measures of noise levels, the results of these surveys can inform cost-benefit analysis of future noise abatement policies in Singapore and provide insights into policies to reduce construction and road noise in other urban centres.

To understand the difference in estimated marginal benefits arising from audio- and text-based representations of noise levels, a sub-sample of the construction noise survey was presented with a text-based questionnaire. The hypothetical scenarios presented to respondents in the text-based questionnaire are similar to the audio-based questionnaire in all respects except that changes to noise levels are described textually. Test questions were included in the

[6] See Chapter 4 for a detailed discussion on survey design and implementation.

text-based questionnaire to test respondents' understanding of the information provided in the questionnaire.

Another challenge in estimating the preferences for noise abatement is that these preferences may vary in the population depending on respondents' demographic background. For example, respondents may have privately invested in noise abatement, resulting in different willingness-to-pay for publicly-provided noise abatement. Further, different segments of the population may have different sensitivity to noise. Different respondents may also have differing exposure to noise, leading to different experiences and consequently differing willingness-to-pay. As such, preferences for noise abatement may be heterogeneous and the survey questionnaire was designed to estimate these sources of heterogeneity.

Results from the audio- and text-based questionnaire contribute to the literature by estimating the effect of respondents' understanding of the survey questionnaire on preferences for noise abatement. Previous studies have found that different presentation methods affect estimated marginal benefits. The surveys conducted in this thesis enable the analysis of respondents' understanding of different representations of noise as a factor causing the heterogeneous preferences for noise abatement. Respondents to the audio-based survey perceive changes to noise level directly and do not need to understand textual descriptions of noise levels. By comparison, respondents to the text-based survey have to read and understand the textual descriptions of noise levels. If respondents do not understand the textual descriptions, the estimated marginal benefits of noise abatement may be inaccurately estimated. The difference in marginal benefits estimated from the audio- and text-based survey provide information on whether previous text-based surveys over- or under-estimated the marginal benefits of noise abatement.

Conducting a stated preference survey enables the inclusion of questions to estimate the heterogeneous preferences for noise abatement. Three potential sources of heterogeneity are examined, namely prior private expenditure on noise abatement, respondents' hearing sensitivity and distance between the noise sources (i.e., construction site or road) and receptors (i.e., respondents' residence). These potential sources of heterogeneity are discussed in turn.

The marginal benefits of public provision of noise abatement are dependent on existing privately-provided measures. For instance, respondents who installed abatement measures privately may be less annoyed by noise pollution, resulting in a lower willingness-to-pay. Conversely, respondents who are most affected by noise pollution may selectively install abatement measures privately and have a greater preference for noise abatement. As a proxy for prior private provision for noise abatement, respondents were asked to state their previous expenditure on noise abatement. The relationship between private spending on defensive measures against noise pollution and preferences for publicly-provided noise abatement has not been studied previously.

The audio-based survey questionnaire design enables the administration of a hearing acuity test to ascertain a respondents' hearing sensitivity. Individuals' hearing sensitivity can potentially affect their preference for publicly-provided noise abatement. Noise abatement reduces annoyance from noise pollution and protects an individual's hearing. Hence, preferences for noise abatement may depend on the individual's hearing sensitivity. For example, individuals with more sensitive hearing may have a greater preference for noise abatement as they are more annoyed with noise. These findings contribute to the health economics literature as previous studies indicate that individuals' health status their preferences for morbidity and mortality risk reductions.[7]

Distance between the nearest construction site or road and respondents' home may affect preferences for noise abatement. The distance between the nearest noise source and residences proxy for the disamenities caused by the noise source on the resident. Previous revealed preference studies have used variation in noise levels at different property locations to estimate the implicit price of noise abatement. Further, stated preference studies have attempted to describe changes to noise levels with location change. These studies suggest that prior experience with noise pollution at respondents' homes may affect preferences for noise abatement as compared to respondents who live in a quieter environment. Results from this analysis provide insights into the effect of environmental factors on willingness-to-pay for pollution reduction.

1.4 Structure of the thesis

The remainder of the thesis can be categorised into three parts. The first part, comprising Chapters 2 and 3, provide the conceptual basis of the studies conducted in this thesis. Chapter 2 provides the contextual and theoretical foundations of the cost-benefit

[7] DeShazo & Cameron (2005) examined a wide range of actual and expected morbidity in individuals' demand for health risk mitigation with a stated preference survey. Bleichrodt, Crainich & Eeckhoudt (2003), Fujii & Osaki (2019), and Liu (2004) developed theoretical models that indicate individuals' willingness-to-pay for health risk mitigation increases with the presence of comorbidity.

analysis of noise abatement policy. As outlined in Section 1.2, the information required to ascertain whether noise abatement policies result in a potential Pareto improvement includes the noise transfer and aggregating function, the marginal benefits of noise abatement, and the marginal costs of noise abatement. Hence, economics and acoustic engineering literature are reviewed. Gaps in the literature valuing the benefits noise abatement are identified.

Chapter 3 develops the research questions. The overarching aim of the research questions is to inform the design of noise abatement policies by providing an estimate of the marginal benefits of noise abatement. The research questions are derived from the gaps in the literature presented in Chapter 2.

Following the discussion of the conceptual basis and research questions, the second part of the thesis (spanning Chapters 4 to 6) describes the development and refinement of the survey questionnaire. Chapter 4 begins this discussion by presenting the random utility model, which forms the basis of the choice modelling methodology. The research design to answer the research questions outlined in Chapter 3 is also discussed.

Chapter 5 uses the theoretical framework introduced in Chapter 4 to design the survey questionnaires. To answer the research questions outlined in Chapter 3, two audio-based questionnaires were designed to estimate the marginal benefits of construction and road noise abatement. Further, a text-based questionnaire was designed to estimate the difference in willingness-to-pay for construction noise when respondents are presented with audio- and text-based questionnaires. The questionnaires also included questions to understand the heterogeneous preferences for noise abatement.

The survey questionnaires designed in Chapter 5 were refined by conducting a series of focus group discussions. Chapter 6 presents the design and findings from the focus group discussion. The focus group discussions provide insights into the disamenities caused by construction activity and roads as well as their preferences for noise abatement. Participants of the focus group discussions also reviewed the draft survey questionnaire. Findings from these discussions enable improvements to the survey questionnaire presented in Chapter 5 to be made. Feedback on the design of the choice sets is particularly important as the design of the choice set was novel.

The third part of the thesis, comprising Chapters 7 to 11, describes the results from the surveys. Chapter 7 begins the discussion of the results from the study by presenting the summary statistics from each phase of the survey. The demographic profiles of respondents are presented and compared with the population in order to understand the representativeness of the survey sample. In order for stated preference surveys to elicit the true preferences of survey respondents, respondents must believe that the scenario provided in the questionnaire is realistic and that results of the questionnaire will affect future policies on noise abatement. Hence, protest respondents and respondents who did not think the survey was consequential are identified and the profile of these respondents are examined.

Chapter 8 is the first of four chapters analysing the results of the choice modelling surveys. This chapter presents the results of the regression analysis from the audio-based construction noise survey. Specifically, the marginal benefit of construction noise abatement is estimated with conditional logit and random parameter logit regression models. The estimated marginal benefits inform the cost-benefit analysis of publicly-provided construction noise abatement.

Chapter 9 compares the results from the audio-based survey presented in Chapter 8 with results from a text-based survey. As discussed in Section 1.3, the text-based survey described changes to noise levels textually and included test questions to ascertain respondents' understanding of the information provided in the survey questionnaire. Comparisons of the results from the audio- and text-based surveys provide insights into the effect of respondents' understanding of the survey questionnaire on their preferences for noise abatement.

Chapter 10 presents the results of regression analysis from the road noise surveys. Similar to the analysis conducted in Chapter 8, conditional logit and random parameter logit regression models were conducted to estimate the marginal benefits associated with road noise abatement. Results from the analysis provide information on the marginal benefits of road noise abatement. The estimated marginal benefits can, in turn, be used to inform cost-benefit analysis of publicly-provided road noise abatement.

Chapter 11 examines the heterogeneity in preferences for public provision of noise abatement. As discussed in Section 1.3, privately-provided noise abatement, hearing sensitivity, and distance between residences and construction sites or roads may affect preferences for noise abatement. Hence, the effects of these factors on the marginal benefits of noise abatement is estimated.

Chapter 12 concludes with a discussion of the main research findings presented in the thesis. This is followed by a discussion of policy recommendations as well as future areas of research. Further, mechanisms to provide efficient levels of construction and road noise abatement are discussed and proposed as future work.

Chapter 2: Benefits and Costs of Noise Abatement

A lack of well-defined property rights results in noise levels that are higher than optimal. Governments can publicly provide noise abatement measures to reduce the impact of noise pollution. However, the welfare change from publicly-provided noise abatement measures is not known to the policy-maker *ex ante*. If the government does not account for the welfare change when designing and implementing policies, publicly-provided noise abatement policies may not improve society's welfare. Consequently, cost-benefit analysis is required to ascertain whether a change in noise abatement policy results in a potential Pareto improvement.

This chapter provides the theoretical basis of a cost-benefit analysis of noise abatement policy. To contextualise the analysis, the chapter begins with a description of noise pollution and its control in Singapore in Section 2.1. Given the context of noise abatement in Singapore, Section 2.2 discusses the cost-benefit analysis framework. Parameters in this framework include: (i) the marginal benefits associated with noise abatement, (ii) the marginal costs associated with noise abatement, (iii) the noise transfer function, and (iv) the noise aggregation function. A review of the literature was conducted to understand previous research into each of the parameters in the cost-benefit analysis framework. Section 2.3 reviews the non-market valuation literature to understand how previous studies estimated the marginal benefits of noise abatement. Section 2.4 presents an overview of previous studies estimating the marginal costs of noise abatement. The acoustic engineering literature is reviewed in Section 2.5 to understand the physical characteristics of noise and provide information on the noise transfer and aggregation functions. Section 2.6 identifies gaps in the literature, providing a basis for the research conducted in the remainder of this thesis.

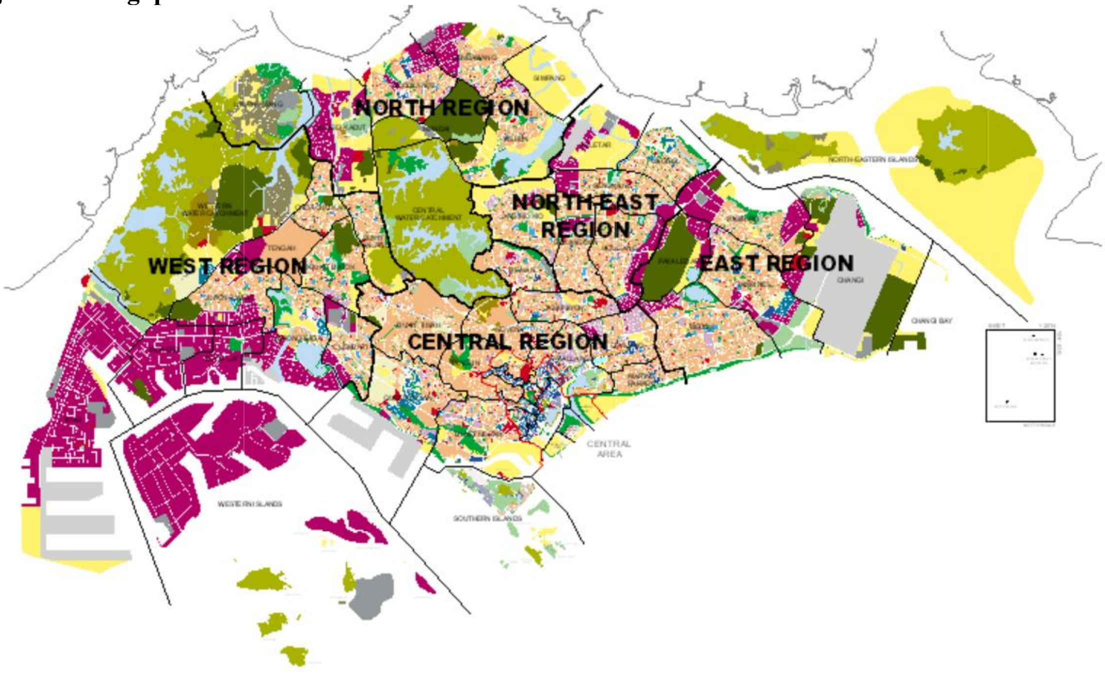
2.1 Noise pollution and control in Singapore

Two key sources of noise in Singapore are from construction activity and roads. As a result of high population density and continued economic growth, Singapore's residents are exposed to a large number of construction sites and an extensive road network. In total, there were around 4,700 active construction sites in 2018 (BCA 2018). The number of construction sites is symptomatic of Singapore's continued infrastructure development to meet the demands of a growing economy. Since 2011, Singapore has embarked on an extensive infrastructure expansion programme. For example, the government is expanding Singapore's rail transit network, collectively known as the Mass Rapid Transit (MRT) (LTA 2015b, 2016). The government is also constructing new housing developments in both new towns and matured development estates (HDB 2016).

Further, an increasing proportion of Singaporeans live in suburban housing estates located outside the city centre. In order to provide connectivity for residents, the road network has also been gradually expanded. Consequently, around 12% of Singapore's land area is dedicated to roads (MOT 2017). In total, around 9,000 lane-km of roads have been constructed in Singapore, with plans to build more roads and expand existing roads in the future.

In contrast to construction and road noise, noise from industry and aircraft have a smaller impact on liveability in Singapore due to land-use planning (Foo 1996; Seetoh & Ong 2008). The current land-use plan of Singapore, depicted in Figure 2-1, indicates that industry and airports are zoned to be away from residences. Notably, Changi International Airport, Singapore's largest airport, is located in the east of Singapore island, away from residential areas. Further, flight paths to the airport are over the Straits of Singapore, reducing the effect of aircraft noise on residents (Changi Airport Group 2018). Similarly, heavy industry is located in western Singapore and off-shore on Jurong Island. The physical separation of residences from heavy industries reduces the effect of noise pollution on residents.

Figure 2-1 Singapore's 2014 Master Plan



Note: Changi Airport is the grey area in the East Region. Heavy industries and residences are represented by magenta and beige respectively. Source: URA 2018.

There are also plans to reduce the impact of existing sources of noise. For instance, the government has announced plans to relocate aircraft at the Paya Lebar[8] military airbase from its current location in the north-east of Singapore to airbases in the west and east of Singapore by 2030. The relocation will reduce noise pollution for residents in the north-east of Singapore.

Nonetheless, noise levels in Singapore remain elevated. Martin & Diong (2017) measured the outdoor sound levels around Singapore's neighbourhoods by taking 18,768 sound measurements over a 2.5 month period between Dec-16 and Feb-17. They found that more than 90% of Singapore's population was exposed to noise levels that exceed the World Health Organisation's (WHO) threshold for serious annoyance (i.e., 55 decibels (dB) over a 16-hour period). By comparison, data from the European Environment Agency (EEA) indicates that only a quarter of the European Union's population was exposed to a similar level of noise (EEA 2018). Martin & Diong also found that 27% of Singapore's population was exposed to noise that exceeded the WHO's limit for hearing impairment (i.e., 70dB over a 24-hour period).

The level of noise has also led to complaints from residents. For instance, in 2015, Singapore's National Environment Agency (NEA) received more than 16,000 complaints related to noise (Tay 2015). Further, there have been frequent letters to the forum pages in the

[8] The current location of Paya Lebar airbase is a legacy of land-use plans prior to Singapore gaining independence. Paya Lebar airbase originally opened in 1954, 11 years before Singapore attained independence.

mainstream media regarding noise pollution (see, for example, Bin (2019), Chan (2017), Chen (2018), Ramamurthy (2018), Tan (2019), Wong (2019), Yun (2018)). These complaints suggest that noise pollution is a source of annoyance for residents.

Regulations of construction and road noise are enforced by the National Environmental Agency (NEA) and the Land Transport Authority (LTA) respectively. Both agencies rely on command-and-control type regulations to prescribe permissible noise emissions. Specific to construction noise, sites located within 150m of residential buildings are permitted to emit noise that is lower than 75dB on average in a day[9], averaged across 12 hours as measured from the façade from the nearest residential building (Singapore Statutes 2011). More stringent noise controls are imposed for construction work at night and on Sundays and public holidays when more people are at home. Furthermore, to regulate the peak level of noise over shorter intervals, the five-minute average sound pressure level is capped at 90dB. More stringent regulations are enforced if the construction site is located close to noise-sensitive buildings such as hospitals and schools.

In order to reduce construction noise below the regulatory limits, NEA introduced the Quieter Construction Fund (QCF) in 2014 (NEA 2016). The QCF incentivises construction companies to reduce noise at their sites by subsidising the purchase or lease of quieter equipment as well as the installation of temporary noise barriers. The QCF also encourages companies to use innovative methods to reduce construction noise by subsidising companies that retrofit existing equipment with noise reducing fixtures or implement active noise control devices. S$10 million was set aside for the implementation of the QCF to be disbursed between 2014 and 2019, of which S$5.1 million was utilised by construction companies (Ng 2019). The QCF was replaced with the Quieter Construction Innovation Fund (QCIF) in 2019, which set aside S$2 million to be utilised over two years (Tay 2019). The aims of the QCIF are the same as those of the QCF (NEA 2019).

Singapore's construction noise regulations demarcate two property rights regimes. In the first regime, the sound pressure level experienced by residents is above 75dB, averaged over a 24-hour period. In this case, households have the right to a quieter environment as construction companies are not permitted to exceed this threshold. However, when the sound

[9] Day-time is defined to be between 7am and 7pm. The logarithmic average of noise emitted over the course of the day is calculated by construction companies. This regulation limits the duration of noisy activity a construction site can engage in over the course of a day. For example, if the logarithmic average of noise from a site is 85dB at 10am, then for the remainder of the day, the construction site can only undertake activity that is emits noise less than 60dB on average.

pressure level is below the regulatory limits, households do not have the rights to a quieter environment. If households prefer to enjoy a quieter environment below 75dB, they will have to pay for noise abatement measures. The notion that property rights lie with construction companies below 75dB is reinforced by the Quieter Construction Fund, which seeks to reduce noise below the regulatory limits by subsidising the purchase of quieter construction equipment (NEA 2016).

Control of road noise involves regulating the types of vehicles allowed on Singapore's roads as well as any modifications to these vehicles. Specifically, by 2018, all new vehicles in Singapore had to comply with the Euro-VI vehicle standards, which prescribe maximum vehicular noise limits (in addition to emissions of other pollutants) (NEA 2014a, 2014b). LTA also mandates that certain modifications to vehicles are either prohibited or require permission from the Authority (LTA 2017). Prohibited modifications include, among others: installation of air horns, changes to engine capacity, and installation of nitrous injection devices. Modifications that require approval include, among others, changes to the exhaust system (including modifications to the muffler) and installation of turbochargers or superchargers. These modifications can alter the operating characteristics of the vehicle and change its noise emission characteristics. While there is no mandatory maximum level of noise emissions from roads, the target loudness of road noise emissions is 67dB averaged over an hour, measured from the façade of the nearest residential building (Ng 2017).

Since there are no mandatory limits to road noise levels, there are no defined property rights. Consequently, road users effectively have the right to emit noise so long as they comply with vehicular regulations. Nonetheless, LTA recognises that elevated levels of noise cause annoyance for residents. Consequently, LTA is embarking on trials to install noise barriers to reduce the loudness of road noise from expressways and arterial roads that are located in close proximity to residents (LTA 2015a).

2.2 Cost-benefit analysis framework

In this section, cost-benefit analysis of publicly-provided noise abatement is discussed. Since publicly-provided noise abatement is the focus of the research conducted in this thesis, unless otherwise stated, noise abatement measures refer to publicly-provided noise abatement.

Noise pollution arises from the flow of energy between the noise source and the receptor. Consequently, noise pollution will instantaneously cease when the source stops emitting noise (Perman et al. 2003). As such, noise pollution is a flow pollutant that does not accumulate in the environment. Further, the energy released by the noise source is measured by the sound power level[10] (L_w). This energy propagates through the air and the receptor experiences changes in the sound pressure level[11] (L_p) (Bies & Hansen 2009). Consequently, noise pollution is treated as a flow pollutant that does not accumulate in the atmosphere.

2.2.1 Effect of noise emission on residents

Building upon the model presented in Section 1.2, suppose there are I number of residents, experiencing noise from J number of noise sources. The residents are indexed by i and the noise sources are indexed by j.

For noise source j, the baseline sound power level of the noise emitted is defined to be $L^0_{w\,j}$. L_w refers to the sound power level, indexed by the source of the noise, j and the superscript 0 denoting that this is the baseline level of noise emissions. Sound power is measured in watts. However, as the human ear is able to perceive a wide range of sound power, it is more convenient to normalise sound power to sound power level, $L^0_{w\,j}$, which is measured in decibels.[12]

Next, consider the effect of the noise emitted by source j on resident i. The noise perceived by resident i due to the noise emitted by source j is defined by the sound pressure level $L_{P\,i,j}$. L_p refers to the sound power level experienced by resident i due to the noise emitted by source j, and is measured in decibels. Sound pressure is measured in pascals. Similar to sound power, sound pressure is also normalised to sound pressure levels that are measured in decibels.

The magnitude of $L_{P\,i,j}$ is affected by several factors. First, if source j emits a higher sound power level, the noise perceived by resident i will be louder, i.e, $L_{P\,i,j}$ increases as $L^0_{w\,j}$ increases. Second, the loudness of sounds perceived by resident i decreases as the distance between the noise source and resident i increases. Third, the noise may be absorbed along the sound path. This could be due to obstructions along the sound path as well as absorption by the

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[10] The sound power level is a measure of the energy emitted by sound source j per unit time. A detailed description of the sound power level is presented in Section 2.5.1.

[11] The sound pressure level is a measure of the loudness of sound perceived by a receptor. A detailed description of the sound pressure level is presented in Section 2.5.1.

[12] A detailed description of the definition of decibel is provided in Section 2.5.1.

air and the ground. Hence, the contribution of noise source j to the ambient noise level at residence i can be defined to be:

$$L_{P_{i,j}} = \varphi\left(L^0_{w_j}, r_{i,j}, A_{i,j}\right) \tag{2–1}$$

where $r_{i,j}$ is the distance between source j and resident i, and $A_{i,j}$ is the absorption of noise. $\varphi(\cdot)$ is a function describing the relationship between the sound power level of the noise emitted by source j and the sound pressure level of the noise perceived by resident i.

The total sound pressure level of the noise experienced by resident i is a function of the background level of noise, defined to be $L^0_{P_i}$, as well as the noise emitted by the J number of noise sources as perceived at resident i. Hence, the ambient level of noise at resident i can be defined to be:

$$\begin{aligned} L_{P_i}^{max} &= \sigma\left(L^0_{P_i}, L_{P_{i,j}}\right), \forall j \\ &= \sigma\left(L^0_{P_i}, \varphi\left(L^0_{w_j}, r_{i,j}, A_{i,j}\right)\right) \end{aligned} \tag{2–2}$$

where $L_{P_i}^{max}$ is the sound pressure level experienced by resident i in the absence of any abatement measures, measured in dB. $\sigma(\cdot)$ a function which aggregates the ambient level of noise as well as noise from the J number of noise sources.

2.2.2 Preferences for and benefits of publicly-provided noise abatement

Suppose the noise experienced by resident i can be abated by a range of abatement measures. These measures could include mandates by the government for noise sources to implement certain noise abatement measures, such as imposing restrictions on the times-of-day when construction activity is prohibited, mandating the use of quieter construction equipment, and tightening vehicular noise emissions standards.[13]

Denoting the abatement measures implemented by noise source j to be α_j, Equation (2–2) can be re-written to include the effect of abatement measures:

$$L_{P_i} = \sigma\left(L^0_{P_i}, \varphi\left(L_{w_j}, r_{i,j}, A_{i,j}, \alpha_j\right)\right), \forall j \tag{2–3}$$

where L_{P_i} refers to the sound pressure level at that resident i experiences taking into account abatement measures.

[13] The model presented here focuses on publicly-provided noise abatement. The relationship between publicly-provided noise abatement and privately-provided noise abatement is discussed further in Section 11.1.

Equation (2-3) illustrates that action by noise sources, including the emission of noise and the abatement of these emissions, affect the ambient level of noise that resident i experiences. Consequently, when noise sources emit noise, they affect the well-being of residents. However, the absence of well-defined property rights allows noise sources to emit noise without compensating residents for the damages caused by the noise emission.[14]

One option to mitigate the effects of this market failure is the implementation of noise abatement policies by the government. The policy-maker has a range of policy options to reduce noise, such as building noise barriers, mandating the use of quieter equipment, or limiting the time-of-day or day-of-week when noise can be emitted. However, the benefits and costs of these policies are not known *ex ante*. Without an analysis of the costs and benefits of noise abatement, the welfare change attributable to these policies is not known. If the policies mandated by the government decrease welfare, then society is better off without additional government regulations. Hence, a framework for cost-benefit analysis is introduced.

Suppose the government is considering K number of policy options to provide noise abatement measures, each indexed by k. Each policy option is described by a set of attributes, and each attribute takes different values for each policy option. The levels are mapped to a real number and the set of levels associated with each attribute is denoted Z. For all policy options, the price that residents have to pay to enjoy the noise abatement is included as an attribute.

If the preferences of a resident are complete[15], transitive[16], continuous[17] and monotonous[18], then the resident's preference ranking can be mapped to a real-valued utility function (Jehle & Reny 2011). Specifically, a utility function will assign higher numerical values to preferred alternatives. For instance, consider two policy options, k_1 and k_2. Further, assume that alternative k_1 is preferred to k_2. In this case, the utility function will assign a higher

[14] Assuming that residents have property rights to a quiet environment. If sources have the rights to emit noise, then residents have to compensate sources to reduce the level of noise emissions.

[15] Completeness asserts that individuals can examine any two alternatives and decide which alternative is preferred. Hence, for all pairs of alternatives, an individual can decide which alternative is preferred.

[16] Transitivity imposes a particular form of consistency to an individual's pair-wise choice. Suppose there are three choice alternatives, k_a, k_b, and k_c. Transitivity implies that if k_a is preferred to k_b and k_b is preferred to k_c, then k_a will be preferred to k_c.

[17] Continuity ensures that sudden reversals of an individual's preference relation do not occur. Suppose that k_a is preferred to k_b, then choice alternatives that are similar to k_a will be preferred to k_b.

[18] Monotonicity asserts that individuals prefer alternatives with greater provision of more economic goods as compared to alternatives with provision of fewer economics goods. Specifically, suppose that k_a provides more economic goods as compared to k_b, then k_a will be preferred to k_b.

numerical value to k_1 as compared to k_2. Suppose a utility function maps u_{k_1} to alternative k_1 and u_{k_2} to alternative k_2, if k_1 is preferred to k_2, then $u_{k_1} > u_{k_2}$.

The utility function represents the preference ranking for the policy options for noise abatement. Utility functions are not unique as any positive monotonic transformation of a utility function will yield the same preference ranking. For example, suppose a positive real number, λ, is multiplied to the utility function such that λu_{k_1} is assigned to alternative k_1 and λu_{k_2} is assigned to alternative k_2. Utility functions with $\lambda \in \mathbb{R}^+$ can all represent the individual's preference ranking. Hence, utility functions are ordinal and can only represent an individual's preference ranking (Hensher, Rose & Greene 2015; Jehle & Reny 2011).

As such, assuming that the resident's preferences satisfy completeness, transitivity, continuity, and monotonicity, the resident's preference ranking for noise abatement across the K number of policy options to provide noise abatement can be described by a utility function:

$$\begin{aligned} utility_{ik} &= u_{ik}\left(S_i, Z_{ik}\left(z_{ik}, price_{ik}, \left(L_{P_{ik}}(\alpha_{jk}) - L_{P_i}^{max}\right)\right)\right), \forall j \\ &= u_{ik}\left(S_i, Z_{i\mathbb{i}k}\left(z_{i\mathbb{j}k}, price_{ik}, \Delta L_{P_{ik}}(\alpha_{jk})\right)\right) \end{aligned} \tag{2–4}$$

where $u_{ik}(\cdot)$ is the utility function which represents the preferences of resident i for policy option k. The utility function depends on the characteristics of the individual, S_i, and the attributes of the policy that affects resident i, $Z_{i\mathbb{i}k}$. Each attribute is indexed by $\mathbb{i}$ and, in total, there are $\mathbb{I}$ number of attributes. Attributes in the utility function include changes to the sound pressure level perceived by resident i, $\Delta L_{P_{ik}}(\alpha_{jk})$, the price associated with the implementation of $Z_{i\mathbb{i}k}$ that is borne by resident i, denoted $price_{ik}$, and other attributes, $z_{i\mathbb{j}k}$. These other attributes can include variation in noise emissions depending on the time-of-day and the day-of-week in order to reduce the adverse effects of noise at night or over the weekend when more residents are at home.

In order to estimate the marginal benefits associated with the tightening of noise regulation policies, the compensating variation is estimated from Equation (2–4). The compensating variation is the change in income the residents require to reach their initial utility after a change in prices. Since the context of this study is an improvement in the environment, the compensating variation corresponds to the willingness-to-pay for noise abatement.

In order to estimate the change in utility due to a change in the attributes, the total derivative of Equation (2–4) with respect to the attributes is taken:

$$\Delta u_{ik} = \frac{\partial u_{ik}}{\partial price_{ik}} \Delta price_{ik} + \sum \frac{\partial u_{ik}}{\partial Z_{\mathbb{i}ik}} \Delta Z_{\mathbb{i}ik} \tag{2–5}$$

where $price_{ik}$ refers to the price attribute and each other attribute is indexed by $\mathbb{i}$.

The compensating surplus is estimated when there is no change in utility, hence, $\Delta u_{ik} = 0$. Consequently, the marginal benefits for a change in the level of attribute $\mathbb{i}$ for resident i, denoted to be $MB_i(Z_{\mathbb{i}ik})$, is:

$$\begin{aligned} MB_i(Z_{\mathbb{i}ik}) &= \frac{\Delta price_{ik}}{\Delta Z_{\mathbb{i}ik}} \\ &= -\frac{\partial u_{ik} / \partial Z_{\mathbb{i}ik}}{\partial u_{ik} / \partial price_{ik}} \end{aligned} \tag{2–6}$$

Specific to changes in ambient noise level, the marginal benefits function associated with a unit change in noise levels due to noise abatement policies is:

$$MB_i\left(\Delta L_{P_{ik}}(\alpha_{jk})\right) = -\frac{\partial u_{ik} / \partial \Delta L_{P_{ik}}(\alpha_{jk})}{\partial u_{ik} / \partial price_{ik}} \tag{2–7}$$

The benefits associated with abatement policies can be estimated from Equation (2–6). For example, consider a policy to publicly-provided noise abatement such that the ambient level of noise is reduced by $\widehat{\Delta L_{P_{ik}}}$. The benefits associated with this measure is the integral between the status quo and $\widehat{\Delta L_{P_{ik}}}$ level of reduction in noise level:

$$B_i = \int_0^{\widehat{\Delta L_{P_{ik}}}} MB_i \, \mathrm{d}\Delta\left(\Delta L_{P_{ik}}\right) \tag{2–8}$$

Total benefits (B) for the whole of society is obtained by aggregating across all residences and assuming that benefits are linearly additive across residences. Hence, the total benefits of abatement are:

$$B = \sum_{i=1}^{I} B_i \tag{2–9}$$

2.2.3 Costs of public provision of noise abatement

Costs of changes to publicly-provided noise abatement policies are borne by the noise source to meet the regulations imposed by the government. Each noise source can choose to implement a range of abatement measures, denoted as α_{jk}. The total cost associated with α_{jk}

level of abatement is represented by the cost function, $C_j(\alpha_{jk})$, which is measured in dollars. The cost function maps each abatement measure to the costs required to achieve this level of abatement.

Each noise source chooses the amount of abatement, α_{jk}, necessary to meet the level of noise emissions mandated by the government. Across the whole of society, the total costs (C) of implementing a noise abatement policy is measured in dollar terms by summing the costs across all noise sources. Hence, the total costs of abatement are:

$$C = \sum_{j=1}^{J} C_j \tag{2–10}$$

2.2.4 Potential Pareto improvement due to noise abatement

For society to enjoy a potential Pareto improvement from the implementation of noise abatement measures, it is necessary to ensure that the marginal benefits arising from these abatement measures outweigh the costs of the measures. The difference between the total benefits and total costs of noise abatement is the net benefits associated with abatement:

$$\begin{aligned} Net\ Benefits &= B - C \\ &= \sum_{i=1}^{I} B_i - \sum_{j=1}^{J} C_j \end{aligned} \tag{2–11}$$

Consequently, when net benefits are positive, society enjoys an improvement to welfare since the benefits accrued to residents outweigh the costs of implementing the noise abatement measures. Conversely, when net benefits are negative, society incurs a net cost to implement the noise abatement measure. As such, noise abatement should be implemented only when net benefits are positive.

Ideally, the optimal level of noise abatement from each source should be chosen so that the net benefit defined in Equation (2–11) is maximised. Assuming that Equation (2–11) is differentiable, the necessary condition obtained when the first-order derivative is equal to zero:

$$\frac{d\sum_{i=1}^{I} B_i}{d\alpha_{jk}} - \frac{d\sum_{j=1}^{J} C_j}{d\alpha_{jk}} = 0 \tag{2–12}$$

or, equivalently,

$$\frac{d\sum_{i=1}^{I} B_i}{d\alpha_{jk}} = \frac{d\sum_{j=1}^{J} C_j}{d\alpha_{jk}} \tag{2–13}$$

which states that in order to maximise the total net benefits of noise abatement, the marginal benefits of abatement should equate the marginal costs of abatement.

In order for Equation (2–13) to provide maximisation of net benefits, the marginal benefits of abatement must be diminishing and the marginal costs of abatement must be increasing as more abatement is mandated. These assumptions on the second derivatives of the benefit and cost functions are discussed in turn.

For marginal benefits, sensitivity to noise increases as the sound pressure level of perceived noise increases, so it is likely that an increase in L_{P_i} leads to a higher rate of increase in marginal benefits and the second derivative of benefits with respect to L_{P_i} is positive $\left(\frac{\partial^2 b_i}{\partial {L_{P_i}}^2} > 0\right)$. Furthermore, L_{P_i} is inversely related to the noise abatement from each noise source, α_j. Since the ambient level of noise falls as noise abatement increases, the marginal benefits associated with noise abatement falls as the amount of abatement increases and the change in marginal benefits with respect to abatement is negative $\left(\frac{\partial^2 b_i}{\partial {a_j}^2} < 0\right)$.

For marginal costs of noise abatement, noise sources will likely seek to minimise the costs associated with noise abatement. Hence, noise sources will order the measures used to reduce noise from the cheapest measures to the most expensive, leading to costs increasing as the level of abatement increase. This ordering leads the second derivative of the cost function with respect to abatement is positive $\left(\frac{\partial^2 c_j}{\partial {a_j}^2} > 0\right)$.

If the benefits and costs functions fulfil these assumptions, Equation (2–13) provides the theoretical maximum level of net benefits achievable from noise abatement. However, in practice, this level of abatement is unlikely to be achieved. The government typically considers specific noise abatement policies and it is more practical to estimate whether each of these noise abatement policies results in a potential Pareto improvement. Nonetheless, information on the marginal benefits and marginal costs functions are still required to understand whether a policy results in Pareto improvement. Further, since the noise emitted at the source is transferred to the receptor and the receptor can be affected by a variety of noise sources, information on the transfer function and noise aggregating functions are also required.

The marginal benefits and marginal costs functions are informed by the economic valuation literature. The marginal benefits and marginal costs functions draw from different strands of the valuation literature since no markets exist for residents to express their preferences for noise abatement. Consequently, the marginal benefits function needs to be informed by non-market valuation techniques. By contrast, markets exist for the provision of noise abatement and the costs of measures can potentially be valued by observing the market prices of these measures.

The noise transfer and noise aggregating functions depend on the physical characteristics of noise. These functions are informed by the acoustics engineering literature, which provides insights into how noise is transmitted and how noise from different sources can be aggregated to give the perceived sound pressure level of at the receptor.

In the remainder of this chapter, a review of the economic valuation and acoustics engineering literature is presented. This literature review seeks to understand how the parameters of the model presented in this section can be informed by previous research.

2.3 Benefits of noise pollution abatement

Currently, no markets exist for residents to express their preferences for noise abatement. Consequently, the marginal benefits function can only be estimated by non-market valuation techniques. These studies can be broadly categorised into revealed preference studies and stated preference studies (Matos et al. 2013). Revealed preference studies seek to estimate the willingness-to-pay for noise abatement by observing price changes in a proxy market (such as the property market). By comparison, stated preference studies directly ask individuals about their willingness-to-pay for changes to noise levels in a survey.

2.3.1 Revealed preference studies

In a revealed preference study, non-marketed values are estimated through observing data on market behaviour. Examples of revealed preference studies include hedonic pricing and the travel cost method. The theoretical underpinnings of revealed preference studies were outlined in Rosen (1974), which described a model of market behaviour for differentiated goods. Differentiated goods are defined to be goods that are sufficiently similar such that they are regarded as a single commodity in consumers' minds yet exhibit a variety of characteristics such that in equilibrium, different goods command different prices.

Hedonic pricing has been extensively used to estimate the marginal benefits of noise pollution. In a hedonic pricing study, an implicit price function is estimated from the price changes of a marketed good in response to different levels of noise. Examples of marketed goods which could be used to estimate the marginal benefits of noise pollution include differential pricing of residential properties (Bateman et al. 2001; Navrud 2002), different usage of electricity (Agarwal et al. 2016), and variation in wages (Dean 2017).

Among these marketed goods, most studies have focused on estimating the effect of noise on the price of residential properties (Bennett 2011; Navrud 2002). These studies hypothesise that home-buyers will be willing to pay a lower price for a property if the property experiences higher levels of noise as compared to other properties. A commonly used indicator when estimating hedonic price models is the noise sensitivity depreciation index (NSDI), which indicates the percentage decrease in house prices per decibel increase in noise levels. A review of hedonic studies estimating the NSDI was presented by Bateman et al. (2001). NSDI was found to range between 0.08 to 2.22, although Bateman et al. suggest that the average value is probably at the lower end of this range.

In addition to the housing market, Agarwal et al. (2016) also analysed the effect of construction noise on the consumption of electricity in Singapore. The researchers hypothesised that electricity consumption of residences located near construction sites is higher than for other residences as the residences exposed to construction noise are more likely to close their windows and turn on air-conditioning. The researchers found that electricity consumption by households living close to construction sites increase electricity consumption by 6%. Further, they find persistent effects of construction activity, even after the completion of construction activities.

Dean (2017) sought to investigate the effect of industrial noise on workers in developing countries. The researcher recruited textile workers in Kenya and varied the noise levels in a factory by generating additional noise in the factory. Results of the study indicate that a 10dB increase in noise levels decreases worker productivity by around 5%. This decrease in productivity is mainly due to the increased noise levels impeding the cognitive function of workers.

While a large number of revealed preference studies have been conducted, the majority of these studies have not estimated the marginal benefits of publicly-provided noise abatement. These studies suffer from several shortcomings. First, noise pollution may be correlated with other amenities or disamenities which affect house prices. For instance, houses which experience higher levels of noise pollution as they are located near roads may also experience higher prices due to the connectivity afforded by the road. Further, construction sites and roads may also cause other disamenities beyond noise pollution, such as visual disamenities and higher concentrations of dust. Estimates from the hedonic pricing method may conflate these disamenities with noise pollution.

Second, noise abatement can be provided privately or by the government. However, revealed preference studies may not be able to estimate the marginal benefits of publicly-provided noise abatement. For instance, if electricity was used as the proxy market, then the marginal benefits estimated from the study refer to the benefits associated with the private provision of noise abatement. Use of these estimates in designing publicly-provided noise abatement policies implicitly extrapolate the marginal benefits of privately-provided noise abatement to publicly-provided noise abatement. If privately-provided noise abatement only reduces indoor noise, then the scope of privately-provided noise abatement is smaller than publicly-provided noise abatement since publicly-provided noise abatement can potentially reduce outdoor noise. Consequently, extrapolation of privately-provided noise abatement may understate the willingness-to-pay for publicly-provided noise abatement. Further, if the housing market is used as the proxy market, then the estimated marginal benefits incorporate both publicly- and privately-provided noise abatement. For example, a house located near a road with a noise barrier may also have installed double-glazed windows. In this case, the estimated marginal benefits will overstate the benefits associated with publicly-provided noise abatement, unless the privately-provided noise abatement can be observed. However, administrative data on privately-provided noise abatement measures are not available in Singapore.

Third, implicit prices are sensitive to model specification and different specifications of the functional form of the implicit price function could also lead to differing estimates of the NSDI. Kuminoff, Parmeter & Pope (2010) conducted a Monte Carlo simulation of different functional forms and found that standard linear models can be improved with the use of more flexible functional forms that use a combination of spatial fixed effects, quasi-experimental specification and temporal controls. Nonetheless, Navrud (2002) suggests that hedonic pricing studies still rely on log-normal functional forms. Further, Bateman et al. (2001) found that omitted attributes had a significant effect on NSDI estimates. Specifically, if only the characteristics of the house were included, NSDI was found to be 0.84. NSDI fell to 0.57 and 0.42 with the inclusion of neighbourhood characteristics and accessibility variables, falling further to 0.2 when controlling for visual disamenities.

Fourth, the accuracy of the revealed pricing method in eliciting the benefits associated with noise abatement is predicated upon potential home-buyers having information about the level of noise in the prospective home (Navrud 2002). If potential home-buyers are unable to perceive the level of noise in the prospective home, they may not price the external costs associated with noise pollution into their bid for the new home. For instance, prospective home-owners who only inspect homes in the night may not know the noise level over the course of the day.

Fifth, Rosen's (1974) model of differentiated goods assumes perfect competition in the market for the differentiated good and zero transaction cost. In reality, these assumptions may not be satisfied, particularly in the property market, where government regulations may restrict the sale and purchase of properties. Transaction costs may also be significant in the property market. For instance, when purchasing properties, it is necessary to incur transaction costs to provide conveyancing services.

Sixth, Rosen (1974) highlighted that the implicit price function is not a measure of welfare gain as the price is jointly determined by both the demand and supply of the proxy good. This simultaneous determination of prices by the demand and the supply side leads to endogeneity when estimating the implicit price function for noise pollution. Consequently, Rosen suggests the use of demographic details of both buyers and sellers as exogenous shift variables in a simultaneous system of equations. Hence, the estimation procedure involves a first-stage where the implicit price functions are estimated, with the inclusion of the exogenous shift variables, followed by a second stage, where the simultaneous demand and supply system is solved. However, researchers rarely have access to individual-level data of buyer and sellers in the property market. As such, Parmeter & Pope (2013) observed that most studies examined the implicit price function without estimating the second stage to determine the welfare gains. Nonetheless, research that conducted the second-stage regression found that the recovered preference parameters were heterogeneous among agents. For example, von Graevenitz (2018) examined the preferences for road noise reduction in Copenhagen, Denmark and found that the recovered preference parameters exhibited heterogeneity across households. Controlling for observed demographic characteristics accounts for only 40% of this variation in preferences for a quieter environment.

Finally, Klaiber & Smith (2011) proposed an extension to Rosen's (1974) model with a general equilibrium model. Klaiber & Smith's model recognises the mobility of households depend on both changes in environmental factors as well as changes in prices of residences. The effect of price changes on demand for residences is particularly important if home-owners are purchasing properties for the asset value of the property. As the researcher may not observe the motives for home purchase, i.e., whether the home is purchased for occupation or for investment, a naïve model of the NSDI may be an incorrect estimate of the marginal benefits of noise abatement.

In summary, revealed preference studies can only identify the marginal benefits associated with noise abatement if detailed demographic details of the house-buyers and house-sellers are known. Further, in order to estimate the marginal benefits associated with publicly-provided noise abatement in revealed preference studies, information on privately-provided noise abatement is also required. These data sources are not publicly available in Singapore from administrative sources, precluding the use of the revealed preference method to estimate the marginal benefits of noise abatement.

2.3.2 Stated preference surveys

Stated preference approaches to valuing the environment were developed partly in response to the shortcomings of the revealed preference method. The stated preference approach to value non-marketed environmental harms can be broadly categorised into contingent valuation and choice modelling studies (Kolstad 2000; Perman et al. 2003).

Contingent valuation studies aim to elicit the valuation of an environmental good by presenting respondents with a hypothetical change in the environment and asking individuals if they would be willing to pay for that change. A set of guidelines established by Arrow et al. (1993) suggests that a contingent valuation survey should first establish the environmental issue and set this issue in the context of the policy framework. Next, a solution to the environmental issue is proposed and a plausible payment vehicle presented to the respondent. The respondent is then asked about their willingness-to-pay. The socio-economic characteristics of the respondent should also be elicited as well as follow-up questions on whether the participant is responding with a protest vote.

Choice modelling studies extend contingent valuation studies by presenting respondents with a series of choice situations. These choice situations are designed with a fixed set of attributes, but each alternative in the choice situation will contain combinations of different levels of the attributes. Respondents will be asked to choose their preferred alternative in each choice situation. Analysis of respondent choices provides an estimate of the willingness-to-pay for the attributes used to describe the policy options.

Choice modelling exploits the fact that individuals make decisions by comparing different alternatives and selecting the alternative they prefer (Hensher, Rose & Greene 2015). Lancaster (1966) suggested that these alternatives can be described by underlying attributes and the individual's utility can be defined in terms of these underlying attributes. For instance, an individual may state that she prefers a particular policy to reduce noise. The individual may prefer a policy because the policy reduces noise by the largest amount as compared to other policies, the policy reduces noise when the individual is at home (and therefore most affected by noise), or the policy is the cheapest as compared to other policies. The choice made by the individual provides insight into which of these attributes drives individual choice and analysis of the individual's choice could reveal her preferences for these attributes.

Similar to contingent valuation studies, choice modelling questionnaires explain the environmental issue and policy context to survey respondents. The choice modelling questionnaire then presents respondents with a plausible payment vehicle before eliciting the demographic details of the participant as well as whether the participant is lodging a protest response. However, unlike contingent valuation studies, the choice modelling questionnaire presents a series of choice situations to the respondent. Each choice situation comprises several different alternatives, which are in turn designed based on a set of attributes. The different alternatives in each choice situation have different combinations of values for the attributes (Wardman & Bristow 2004).

In order for stated preference studies to elicit accurate non-market values of environmental goods, respondents need to understand the information provided in the survey questionnaire. Further, the environmental issue and proposed solution to this issue has to accurately describe the real-world situation (Rolfe, Bennett & Louviere 2000). Conversely, a scenario that does not accurately describe the real-world situation would result in valuations which may not represent the actual valuation of the respondent. Similarly, the accuracy of the willingness-to-pay estimates from choice modelling studies is predicated on respondents understanding the hypothetical policy change as well as their understanding of the changes to the attributes (Hanley, Mourato & Wright 2002; Hoyos 2010). Previous choice modelling studies which sought to value the benefits associated with noise abatement attempted to describe textually the change in noise levels with explanations similar to those used in contingent valuation surveys.

Previous stated preference studies described noise levels textually. As the physics of noise is complex (see Section 2.5 for details on the measurement of noise), a wide range of textual descriptions has been developed to communicate changes to noise levels to respondents. These textual descriptions can be broadly categorised into changes to the physical units of noise, changes to levels of annoyance, and changes to contexts. These categories will be discussed in turn.

2.3.2.1 Changes to physical units of noise

Stated preference surveys have used physical units of noise levels to describe changes to noise levels. For instance, Garrod, Scarpa & Willis (2002) estimated the benefits associated with the reduction of vehicular speed limits in the UK. Among other externalities, they presented respondents with a change in sound pressure levels (i.e., 60, 70, and 80dB). Studies have also asked respondents if they were willing to pay for a proportional change in the level of noise. Pommerehne (1988) and Soguel (1996) conducted contingent valuation surveys in Switzerland and asked respondents whether they were willing to pay to reduce noise pollution in the vicinity of their house by half. Further, Sælensminde & Hammer (1994) and Sælensminde (1999) conducted choice modelling surveys in Norway to ascertain respondents' willingness-to-pay for changes to the environment arising from a change in fuel type. The researchers described the change in noise levels to respondents in terms of a percentage reduction in noise.

A criticism of these studies is that the respondents may not understand the described noise levels. For instance, focus groups discussion conducted by Galilea & Ortúzar (2005) found that respondents did not know the interpretation of the decibel scale or understand the logarithmic nature of the scale. Further, a proportional change in noise levels is subjectively interpreted by survey respondents and the analyst cannot observe the change in noise levels respondents have in mind when they are answering the survey questionnaire (Arsenio, Bristow & Wardman 2006).

2.3.2.2 Changes to annoyance levels

Studies have also attempted to estimate the willingness-to-pay in terms of the annoyance caused by the noise. The use of annoyance as a measure of road noise reduction introduces difficulties when translating these valuations into policy decisions. In practice, policies to reduce noise are typically implemented based on a target reduction in sound pressure levels, measured in dB. However, if the valuation is obtained in terms of a willingness-to-pay to reduce annoyance, the government will have to translate benefits of noise reduction to benefits of annoyance reduction – which may be difficult to ascertain.

Early studies asked respondents about annoyance from common noise sources. This enabled the researchers to estimate a correlation between noise levels in decibels and annoyance levels. Navrud (2000) provided respondents with a detailed list of the adverse effects of noise pollution in terms of discomfort. Respondents were then informed that the proposed policy would have the following effects: (i) eliminate noise annoyance indoors, (ii) provide a 50% reduction of noise annoyance outside their dwelling, and (iii) eliminate noise in parts of a nearby recreational forest. The researcher also asked respondents about their annoyance associated with common indoor and outdoor noise on a standardised annoyance scale. Responses were analysed to establish a correlation between annoyance and the physical measure of noise.

Studies have exploited advances in noise measurement technology to estimate the background noise exposure experienced by participants and correlate the background levels of noise to levels of annoyance. Lambert & Champelovier (2001) asked respondents about their willingness-to-pay to eliminate annoyance from noise pollution within their homes. Lambert & Champelovier also asked respondents to rate the level of annoyance they faced at their homes on a five-point Likert scale. The researchers then recorded noise at the respondents' home over a 24-hour period in order to correlate the annoyance scale with a physical measure of noise. Galilea & Ortúzar (2005) used a ten-point scale of annoyance in their choice modelling survey. In order to estimate the relationship between annoyance and loudness of sounds, Galilea & Ortúzar also measured the background noise of 96 respondents. They then estimated a linear relationship between annoyance and loudness. Li et al. (2009) extended the Galilea & Ortúzar study with a more extensive noise recording protocol. Specifically, Li et al. recorded the loudness of the background noise faced by every participant. Li et al. then estimated the relationship between annoyance and loudness with an ordered probit regression, taking into account respondent demographics.

Studies have also used acoustic modelling techniques to relate annoyance levels with physical measures of noise. Fosgerau & Bjørner (2006) augmented their contingent valuation survey dataset with a socio-acoustic survey to ascertain the background level of noise in respondent homes. They then asked respondents questions related to the level of annoyance with noise pollution before eliciting the willingness-to-pay for silencing the noise pollution. Similarly, Bravo-Moncayo et al. (2017) also estimated the noise exposure of respondents by modelling the road condition, taking into account variables such as road traffic flow, average speed and the composition of traffic flow. A contingent valuation survey was then conducted to ascertain the willingness-to-pay for a reduction in annoyance associated with noise, controlling for the background level of noise faced by respondents.

Physiological evidence has also been used to correlate annoyance reduction with changes in a physical measure of noise abatement. Kim et al. (2019) conducted a contingent valuation survey asking Korean respondents whether they were willing to pay to reduce noise to a level that reduced noise levels completely. The research estimated the willingness-to-pay for one-decibel of noise reduction by using the average noise level as the upper bound and 42dB as the lower bound, arguing that 42dB corresponds to the European Environment Agency's (EEA) threshold for sleep disturbance (EEA 2017).

While these studies have attempted to correlate the valuation of annoyance reduction to the benefits of a physical measure of noise, the data required for such a correlation may be difficult to obtain. If the survey included additional questions on the annoyance associated with common noise sources, respondents must accurately remember the loudness of these different noise sources. However, Galilea & Ortúzar (2005) found that when respondents were asked to rank, from memory, road intersections with objectively different levels of noise, their responses did not correlate with the actual level of noise at the intersections, indicating that respondents' memory of noises may not be precise. Further, noise measurement and acoustic modelling of urban areas require extensive data collection at respondents' homes. Finally, the transfer of annoyance levels from physiological studies imposes strong assumptions on respondents' annoyance with noise. Specific to Kim et al. (2019), all respondents are assumed to have a lower annoyance threshold of 42dB, which may not be accurate given that this threshold was transferred from a European context to estimate annoyance thresholds in Korea.

2.3.2.3 Changes to contexts

Studies have also attempted to use changes in context to describe different noise levels. These studies compare the noise levels with situations that respondents may encounter in reality. For instance, Barreiro, Sánchez & Viladrich-Grau (2005) surveyed individuals in Pamplona, Spain, and explained the change in noise levels in terms of noise experienced at different times of the day and on different days of the week. Specifically, the researchers asked respondents if they were willing to pay for a reduction in noise levels from ‘a working day during working hours and the same day at 9:30pm’ as well as ‘a working day during working hours and a Sunday morning’. The researchers then estimated the willingness-to-pay for a decibel of noise abatement by referencing the average sound levels in the neighbourhood.

Another method to describe the change in noise levels to respondents is to describe specific noise abatement policies and the outcome of these policies. For instance, Vainio (2001) presented respondents with a scenario where traffic was diverted elsewhere due to the construction of a tunnel, which will result in traffic volume diminishing considerably and the street becoming a ‘residential street’. Huh & Shin (2018) also asked respondents about their willingness-to-pay to implement policies that reduce road noise or community noise.

Wardman & Bristow (2004) described changes in noise levels with percentage changes in the loudness of noise to value the benefits associated with noise abatement in Edinburgh, UK. In addition, Wardman & Bristow used a locational proxy to describe air pollution levels. Specifically, respondents were asked to value a change in the level of pollution from the level they experience in their homes to a level experienced at another location. Arsenio, Bristow & Wardman (2006) extended on Wardman & Bristow (2004) by describing changes to the level of noise pollution with a locational proxy. Arsenio, Bristow & Wardman exploited the fact that a subset of Lisbon’s housing market comprised of apartments located close to major roads but with variation in noise levels within the same building and lot, depending on the layout of the apartment and the road. The researchers then asked respondents to value the benefits associated with a change in apartment location and used physical measurements of actual levels of noise within apartments to ascertain the willingness-to-pay for noise abatement.

Studies have also used the number of noise incidents as a proxy to describe changes in the level of noise. These studies examine the willingness-to-pay for reduction of aircraft noise and described noise levels by changes to flight schedules. Carlsson, Lampi & Martinsson (2004) described aircraft noise levels with the number of flights per hour at different times of the day. Wardman & Bristow (2008) used a similar description, where changes in noise level are described based on the minutes between planes flying by.

While a wide range of contexts has been used, they tend to be policy- and location-specific and may not be readily applied to all noise sources. Further, the contexts depend on respondents’ subjective interpretation of the magnitude of noise reduction described in the scenarios. For instance, if respondents were asked whether they would prefer to reduce noise levels in their residence during the day to a level they experience at night, it is not clear that respondents are valuing solely the change in the noise levels. Physical measurements of noise at night may be quieter than that of noise in the day, however levels of noise may still be perceived to be high due to fewer other sources of noise as well as the psychological perception that the environment at night should be quiet. Further, if the question is framed based on policies to change the level of noise, the valuation of noise abatement may be confounded with other externalities. For instance, if the scenario presented to respondents is based on a change in the volume of traffic along a road, the valuation of road noise abatement may be confounded with the valuation of dust from the road as well as increased road safety due to lower traffic.

2.3.2.4 Comparison of textual descriptions

Different descriptions of noise levels can lead to different estimated willingness-to-pay for noise abatement. Kaushali, Toner & Chen (2018) estimated the effect of different types of textual descriptions of noise levels on the willingness-to-pay for noise abatement. Specifically, the researchers presented two different survey questionnaires to sub-samples of the survey sample. One sub-sample received a linguistic description of noise (i.e., noisy, quiet and neither noisy nor quiet) while the researchers used a locational proxy to explain noise changes to the other sub-sample. Their results indicated that there was a large discrepancy in the estimated willingness-to-pay depending on the way that the attributes were described to respondents. They found that when respondents were presented with a locational proxy, respondents were willing to pay €0.87 per month for a unit improvement in the perceived loudness of noise. If respondents were presented with a linguistic explanation of noise levels, the willingness-to-pay was €74.8 per month to reduce noise from ‘noisy’ to ‘quiet’. The large difference in valuations corroborates with other choice modelling studies which found that differences in explanation of attributes could lead to differences in willingness-to-pay estimates (Bushong et al. 2010; Kragt & Bennett 2012; Windle & Rolfe 2014).

2.3.2.5 Comparison of stated preference surveys with audiology studies

Previous stated preference surveys could potentially be improved if survey respondents can perceive the changes to the noise levels when making their choices. Unlike textual descriptions, which may be subjectively interpreted by respondents, recordings of noise levels provide an objective description of the changes to noise levels associated with each policy option.

While stated preference surveys attempt to ascertain how willingness-to-pay varies with changes in noise levels, research in audiology attempts to elicit the physiological and psychological effects of noise. In order to elicit the responses to noise, studies from audiology have attempted to elicit responses from individuals by playing noise to respondents, thus eliminating the need to describe the changes in noise levels.

Laboratory experiments conducted in audiology have tended to follow similar design protocols. First, the researcher obtains a recording of the relevant audio stimuli with an audio recorder. This could be achieved by recording the ambient level of noise near the noise source. For instance, if the researcher seeks to record road noise, the researcher could measure the ambient level of noise near roads (see, for example, Cermak (1979), Cermak & Cornillon (1976), Namba & Kuwano (1984) and Yaniv, Danner & Bauer (1982)). Alternatively, researchers could also record the noise generated by the equipment at the noise source. For instance, Rice et al. (1974) recorded the noise generated by heavy commercial vehicles, while Lee, Hong & Jeon (2015) recorded noise generated by different types of construction equipment.

Second, the researcher processes this audio recording to alter the characteristics of the sound. This could involve changes to the loudness of the sound. For instance, Kuwano, Namba & Fastl (1988) and Namba & Kuwano (1984) processed noise from different noise sources to have different levels of loudness. Researchers also vary the frequency of the recorded noise. This is achieved by reducing or amplifying specific frequency bands. For example, Watts (1995) and Nilsson (2007) transformed the recorded noise by increasing the loudness of noise between 1 and 2.5kHz by up to 15dB. Changes to frequency could also be achieved by combining different sound clips (see, for example, Rice et al. (1974) and Lee, Hong & Jeon (2015)).

Third, processed stimuli are presented to respondents. This could be accomplished with speakers, headphones or a combination of both. For instance, Cermak (1979), Cermak & Cornillon (1976) and Rice et al. (1974) used speakers in a soundproof room to simulate sounds to participants in their studies. Kuwano, Namba & Fastl (1988), Lee, Hong & Jeon (2015) and Namba & Kuwano (1984) used headphones while Nilsson (2007) used headphones as well as a subwoofer when playing sounds back to the respondent.

Beyond laboratory experiments, studies have also attempted to measure the psychological and physiological effects of noise with field studies. Field studies measure participant response to noise in either outdoor areas or in the homes of participants. Stansfeld & Matheson (2003) reviewed studies examining the non-auditory impact of noise and found that responses in the field may be different from the laboratory. For instance, exposure to transport noise disturbs sleep in the laboratory, but not generally in field studies. Stansfeld & Matheson hypothesised that the difference in response may be due to some adaption to noise pollution over time.

2.3.3 Heterogeneous preferences of noise abatement

Studies have also attempted to estimate the heterogeneous effects of the survey respondent's experience with noise. For instance, Huh & Shin (2018) and Kim et al. (2019) designed contingent valuation surveys to estimate the willingness-to-pay for transportation noise reduction in South Korea. Huh & Shin included questions on whether respondents have experienced noise, their interest in environmental issues, and the number of infants in the house. Among these factors, prior experience with noise and interest in environmental issues affected the willingness-to-pay for noise abatement. Kim et al. asked respondents about their annoyance with current levels of noise. They found that respondents who were annoyed with the current level levels of noise were more willing to pay for noise abatement.

Nonetheless, other sources of heterogeneity have not been examined by previous studies. A source of heterogeneity arises from differential private investment into noise abatement. It is known that private averting behaviour affects the costs of pollution and, concomitantly, the benefits of pollution abatement (Courant & Porter 1981; Freeman 1979). As a local pollutant with avenues for residents to privately-provide noise abatement, the marginal benefits of publicly-provided noise abatement depend on prior privately-provided noise abatement. Since both privately- and publicly- provided noise abatement reduce noise levels, these abatement measures are substitutes. However, the relationship between willingness-to-pay for publicly-provided noise abatement and prior spending on abatement measures is ambiguous. On the one hand, respondents who have privately invested in noise abatement measures may be less annoyed by construction noise and have a lower willingness-to-pay for publicly-provided noise abatement. On the other hand, respondents who are more annoyed by noise pollution may have selectively privately invested in noise abatement. Hence, these respondents may report a higher willingness-to-pay for public provision of noise abatement in spite of prior spending on noise abatement.

A second source of heterogeneity is the effect of hearing sensitivity on noise abatement. Theoretical studies from the health economics literature have found that existing health conditions can influence the willingness-to-pay for health improvements (Bleichrodt, Crainich & Eeckhoudt 2003; Fujii & Osaki 2019; Liu 2004). Further, a choice modelling survey conducted by DeShazo & Cameron (2005) found that respondents' willingness-to-pay for treatment increased demand for life-saving policies and preventive health care.

In a similar vein, willingness-to-pay for noise abatement may also differ depending on an individual's hearing sensitivity. For example, an individual with more sensitive hearing may be more annoyed by noise pollution and therefore report a higher willingness-to-pay for noise abatement. However, no previous study has examined the relationship between preference for noise abatement and hearing sensitivity.

From the audiology literature, an individual's hearing sensitivity can be estimated with a pure-tone audiometry test (British Society of Audiology 2011). In an audiometry test, respondents are presented with a series of test-tones and the respondent indicates the quietest sounds they can perceive. However, previous stated preference studies did not administer such a test.

2.4 Costs of noise pollution abatement

Similar to studies estimating the marginal benefits of noise abatement, the studies estimating the marginal costs of noise abatement are mainly focused on noise from the transportation network, most notably road and rail noise. However, unlike the marginal benefits function, markets exist for the provision of noise abatement and marginal costs can be estimated by observing the market prices of abatement measures.

The government has two options when designing noise control policies, namely command-and-control policies or implementing market-based mechanisms. Under the command-and-control regime, the government can implement two types of policies. First, the government can mandate the implementation of specific noise abatement measures. For example, the government can decide to build noise barriers around construction sites or roads. In this case, the costs of these measures can be weighed against the benefits function to estimate whether the policy will lead to a potential Pareto improvement. Second, the government can limit the maximum level of permissible noise emissions. In order to estimate whether limiting the maximum noise levels achieves a potential Pareto improvement, a cost schedule of potential noise abatement measures needs to be constructed (Kolstad 2000).

The government can also implement market-based mechanisms, such as imposing a fee on noise sources so that the polluters internalise the external costs of noise pollution. If a pollutant is uniformly-mixed flow pollutant that affects all residents equally, then setting the tax level to be equal to the marginal benefits of noise abatement will result in an efficient provision of noise abatement. However, noise pollution is not uniformly mixed as the damage from noise pollution depends on the location of the noise source and receptor.[19] In this case, if the government seeks to achieve an efficient level of noise abatement, the government requires the cost schedule of available abatement measures as shadow prices of noise pollution damage is not uniform (Perman et al. 2003).

Notwithstanding the existence of markets for noise abatement measures, estimation of the costs of individual noise abatement measures and a cost schedule of noise abatement measures is not trivial. The policy-maker likely do not observe the full set of abatement options available for noise abatement and technological improvements can cause the costs to change over time.

Studies examining the costs of noise abatement have mostly been undertaken as part of an attempt to estimate the cost-effective level of noise abatement. For example, Andrew, May & Osman (1980) estimated the least-cost approach to achieve a target noise pollution level of 57dB with noise barriers in Ontario. Specifically, they defined the target level of noise abatement to be $\Delta L_i(L_i - 57)$, where, ΔL_i is the change in noise levels due to the noise barriers and $(L_i - 57)$ is the difference between the current level of noise and 57dB. The researchers then proposed a least-cost approach to noise barrier placement, taking into account the target level of noise abatement and the acoustic properties of noise dissipation. The researchers considered combinations of two types of noise barriers – namely, a 3m high barrier with a nominal cost of US$45 per running foot of barrier and a 4m high barrier with a nominal cost of US$55 per running foot of barrier.

Oertli (2000, 2006) conducted a similar cost-effectiveness analysis of railway noise control. The objective of Oertli's analysis was to estimate cost-effective prioritisation of initiatives to achieve a one-third reduction in the number of people experiencing noise louder

[19] See Section 2.5 for a discussion on the physical properties of noise.

than regulatory thresholds. Oertli's defined the effectiveness of the policy to be $\Delta L_i \times population$, where ΔL_i is the change in noise levels due to abatement policies and $population$ is the population is the number of people who experiences the reduced noise levels. A least-cost abatement policy to achieve the target level of noise abatement was then proposed.

In these studies, the researchers sought to estimate the least cost approach to achieving a target level of noise pollution. Researchers have also attempted to determine the target level of noise pollution by expressing the marginal benefits and marginal costs of abatement in dollar terms. Nijland et al. (2003) estimated the present value of the costs and benefits associated with noise control measures in the Netherlands. The researchers estimated the costs of two types of road noise abatement measures, namely, silent tires and silent pavement on highways as well as main roads. Nijland et al. found that the cost of silent pavement was €3.5 per m^2 of pavement. They estimated that the present value of the costs associated with road noise abatement ranged from €0.86 to €1.4 billion. The researchers also estimated the costs associated with four types of rail noise abatement measures (introduction of silent trains, changes to the braking system, track polishing and silent tracks for new train lines). They estimated the costs of rail noise abatement measures to be around €600 million. For benefits of noise abatement, the researchers used a benefit transfer from meta-analyses of hedonic pricing and contingent valuation studies conducted by Bertrand (1997) and Howarth et al. (2001). Nijland et al. found that the total benefits of noise abatement from all six noise abatement measures exceeded the total costs of these measures.

Similarly, Micheli & Farné (2016) conducted a cost-benefit analysis to estimate the efficient level of rail noise abatement. Micheli & Farné (2016) estimated the costs of two main forms of noise abatement – noise barriers and insulated windows. The researchers estimate that the costs associated with providing incremental noise abatement increases non-linearly and was lower for noise barriers as compared to insulated windows. The costs of noise abatement were then compared with the benefits of noise abatement, which were obtained from a review of the hedonic pricing literature. The researchers found that noise reduction of 15-25dB was optimal.

In summary, previous studies estimated the marginal costs of noise abatement by observing the market prices of these abatement measures. Unlike studies estimating the marginal benefits of noise abatement, these studies did not require the use of non-market valuation techniques. Hence, future reviews of noise abatement policies can similarly obtain marginal costs function by observing the market prices of the noise abatement measures.

2.5 The ambient level of noise

This section aims to provide an overview of the key characteristics of sounds in the context of sound propagation and aggregation of sounds from different sources. The literature reviewed in this section will inform the functional forms of the noise transfer function, and the noise aggregating function. As discussed in Section 2.2, both of these functions are arguments in the marginal benefits function, since the noise emitted by a noise source is transferred to the receptor and each receptor may experience noise from different sources.

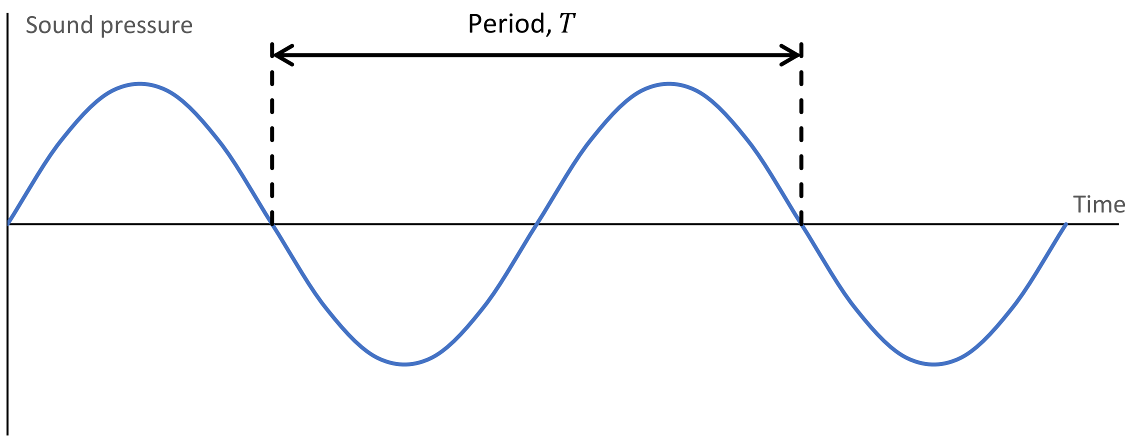
2.5.1 Physics of sound

Before discussing the physics of sound propagation and aggregation, the concepts of frequency, wavelength, and measures of loudness of sounds are introduced.

A sound wave transports energy from the source of the sound by causing particles in space to move back and forth about one position (Bies & Hansen 2009). As sound propagates across space (for the research on construction and road noise conducted in this thesis, the only propagation medium will be air), the sound wave causes measurable fluctuations in the velocity, pressure, temperature, and density of air.

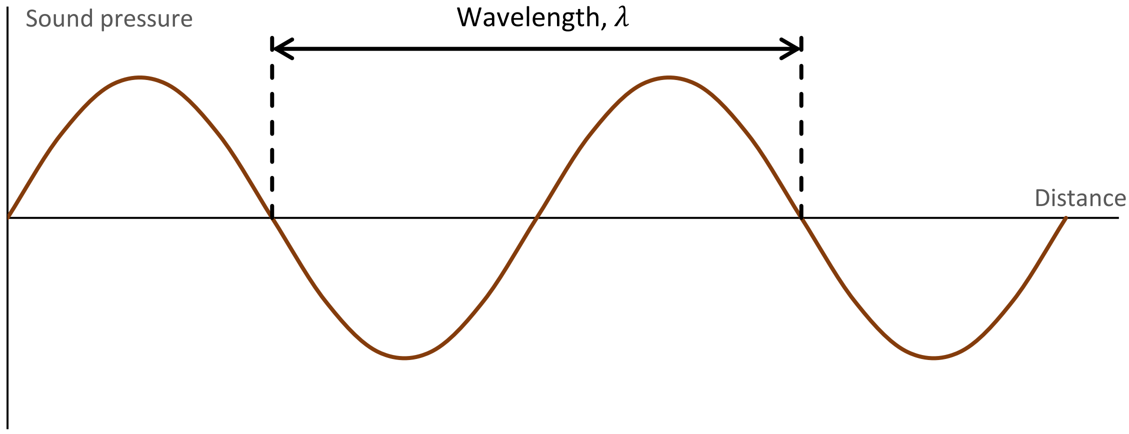
To illustrate the effect of a sound wave on the position of a particle, consider a pure-tone sound with only a single frequency described by a sine wave. The amplitude of oscillations of the particles at a fixed point in space encountering this pure-tone sound is illustrated in Figure 2-2. The period, T, is the time required for the wave to complete one cycle. Further, the frequency, f, is defined as the inverse of the period, i.e., $f = 1/T$.

Figure 2-2 Illustration of the period of a pure-tone sound wave



Similarly, it is possible to trace the pressure distribution in space at any given time (Figure 2-3). In this case, the graph traces the oscillation of particles as the distance from the source vary and the abscissa of the graph is distance. The wavelength, λ, is defined to be the distance between repeating features of the wave. The product of the wavelength and the frequency yields the speed of sound, i.e., $c = f\lambda$, where c is defined to be the speed of sound. The speed of sound in dry air at 20°C is around 343m/s (Zuckerwar & Wong 2002).

Figure 2-3 Illustration of the wavelength of a pure-tone sound wave



The frequency of sounds is related to the pitch of the sound, with higher frequency pure-tone sounds corresponding to a higher pitch. For example, a sound with a frequency of 1kHz will be perceived to have a higher pitch as compared to a sound with a frequency of 0.5kHz. In reality, most noises are complex sounds that comprise of numerous pure-tone sounds. Examples of complex sounds range from human speech and musical instruments to noise pollution from construction activities and roads. The pure-tone frequencies which comprise a complex noise could be obtained by performing a Fast Fourier Transformation (FFT) on the complex noise (Heideman, Johnson & Burrus 1984). Ascertaining the component pure-tone frequencies of a complex noise could give an indication of the characteristic of the complex noise. For instance, if most of the energy content of the complex sound is attributable to low-frequency component pure-tone waves, then the complex sound will be low pitched.

The amplitude of the sound affects the loudness of the sound. One measure of this loudness of the pressure of the sound (Fastl & Zwicker 2007). The higher the pressure of the sound, the larger the amplitude of the sound and the louder the sound. Sound pressure, p, is measured in Pascals (Pa) or, equivalently, force per unit area (N/m^2).

A related measure of loudness is the intensity of the sound (Fastl & Zwicker 2007). Intensity, I, is defined to be the power transmitted per unit surface area perpendicular with a wavefront at a fixed position in space (Lord et al. 1980). The power transfer can be calculated by taking the average of the product of the sound pressure, p, and the velocity, u, of the particles reaching the surface. This can be represented by:

$$I = \lim_{T\to\infty} \frac{1}{T} \int_0^\infty pu\, dt \tag{2–14}$$

The types of noises encountered in this thesis can be approximated to be far-field noise[20] which radiates in one direction and the pressure and velocity are in phase. In this specific case, the velocity and pressure are related by Equation (2–15):

$$u = \frac{1}{\rho c} p \tag{2–15}$$

where ρ is the density of air and c is the speed of sound. ρc is also defined to be the characteristic impedance of the medium.

Substituting Equation (2–15) into (2–14) yields:

$$\begin{aligned} I &= \lim_{T\to\infty} \frac{1}{T} \int_0^\infty p \cdot \frac{1}{\rho c} p\, dt \\ &= \lim_{T\to\infty} \frac{1}{T} \int_0^\infty \frac{p^2}{\rho c}\, dt \\ &= \frac{1}{\rho c} \cdot \lim_{T\to\infty} \frac{1}{T} \int_0^\infty p^2\, dt \end{aligned} \tag{2–16}$$

where $\lim_{T\to\infty} \frac{1}{T} \int_0^\infty p^2\, dt$ is the mean of the square sound pressure. It is also common to express the average sound pressure in terms of the root mean square, i.e., $p_{rms} = \sqrt{\lim_{T\to\infty} \frac{1}{T} \int_0^\infty p^2\, dt}$, as the root mean square pressure has the same dimensions.

Related to the sound intensity is sound power, W. Sound power is the total power transmitted by a noise source. This power could be calculated by integrating the intensity across the surface, S, incident to the noise:

[20] Far-field noise refers to noise that is experienced more than 2 wavelengths away from the source of the noise. The lower bound of human hearing is around 20Hz, which corresponds to a wavelength of around 17m. Consequently, if residences are located further than 34m from the noise source, the noise experienced by residents can be analysed as a far-field noise.

$$W = \int_{0}^{S} I \, dS \tag{2–17}$$

If the noise source is a point source which emits noise equally in all directions (i.e., a non-directional spherical radiator), then the intensity is uniform for any sphere surrounding the source (Lord et al. 1980). The surface area of the sphere is $4\pi r^2$ and the power from the source is:

$$W = 4\pi r^2 I \tag{2–18}$$

For humans, the quietest perceivable sound has a sound pressure of 10^{-5} Pascals (Pa) while the threshold of pain[21] has a sound pressure of 10^{2}Pa (Fastl & Zwicker 2007). Correspondingly, in far-field conditions, the corresponding intensity ranges from 10^{-12}W/m^2 for the quietest perceivable sound to 10^{2}W/m^2 at the threshold of pain.

Given the large range of sound pressures and intensities that can be perceived by the human ear, the sound pressure and sound intensity are commonly expressed in terms of a logarithmic level, measured in decibels (dB) (Bies & Hansen 2009). This logarithmic level is defined to be:

$$10 \log_{10}\left(\frac{power}{reference\ power}\right) \tag{2–19}$$

Hence, the sound power level, L_w, sound intensity level, L_I, and the sound pressure levels, L_p, are defined as follows:

$$L_W = 10 \log_{10}\left(\frac{W}{W_{ref}}\right) \text{dB}, W_{ref} = 10^{-12}\text{watts} \tag{2–20}$$

$$L_I = 10 \log_{10}\left(\frac{I}{I_{ref}}\right) \text{dB}, I_{ref} = 10^{-12}\text{watts} \tag{2–21}$$

$$\begin{aligned} L_P &= 10 \log_{10}\left(\frac{\lim_{T\to\infty} \int_0^\infty p^2 \, dt}{\lim_{T\to\infty} \int_0^\infty p_{ref}^2 \, dt}\right) \\ &= 10 \log_{10}\left(\frac{{p_{rms}}^2}{{p_{rms,ref}}^2}\right) \\ &= 20 \log_{10}\left(\frac{p_{rms}}{p_{rms,ref}}\right) \text{dB}, p_{rms,ref} = 20\mu\text{Pa} \end{aligned} \tag{2–22}$$

[21] The threshold of pain is the quietest sound that is perceived as painful (IASP 2017).

The reference power, intensity, and pressure in Equations (2-20), (2-21), and (2-22) are chosen as they are the threshold of hearing – the quietest sound that can be heard by most people (Fastl & Zwicker 2007). Furthermore, an increase in 1dB is the minimum increment necessary for a noticeably louder sound.

Due to the logarithmic function in the decibel, changes in decibels scale non-linearly with changes in power, intensity, and sound pressure. For example, while a change from 50dB to 60dB represents a 20% increase in decibels, the corresponding increase in sound power and intensity is 1000% and the increase in the root means squared sound pressure is 316%. In terms of perception, a 10dB increase in loudness is equivalent to a doubling of perceived loudness for sounds with sound pressure levels of at least 40dB (Fastl & Zwicker 2007). Consequently, a change from 50dB to 60dB represents a doubling in perceived loudness.

2.5.2 Propagation of noise

In order to derive the relationship between sound pressure levels and distance, consider a noise source which emits noise with equal power in all directions. In this case, the relationship between the power of the source and the intensity is given by Equation (2–18). Further, substituting into the definition of sound power level, Equation (2–20), yields:

$$L_w = 10\log_{10}\left(\frac{4\pi r^2 I}{W_{ref}}\right) \tag{2–23}$$

Assuming that the distance between the noise source and receptor is sufficiently far apart so that the noise can be described as a far-field noise, the relationship between intensity and pressure is given by Equation (2–16) and substitution into (2–23) yields:

$$L_w = 10\log_{10}\left(\frac{4\pi r^2 \lim_{T\to\infty}\int_0^{\infty} p^2\,dt}{\rho c W_{ref}}\right) \tag{2–24}$$

which can be rewritten in terms of root mean squared sound pressure:

$$L_w = 10\log_{10}\left(\frac{4\pi r^2 p_{rms}^2}{\rho c W_{ref}}\right) \tag{2–25}$$

The root mean squared of the sound pressure in Equation (2–25) refers to the sound pressure at distance r from the source of the noise. Hence, rearrangement of Equation (2–25) in terms of sound pressure level will yield the relationship between sound pressure levels, sound power levels and distance:

$$L_w = 10\log_{10}\left(\frac{p_{rms}^2}{p_{rms,ref}^2}\right) + 20\log_{10}(r) + 10\log_{10}\left(\frac{4\pi p_{rms,ref}^2}{\rho c W_{ref}}\right) \qquad (2–26)$$

$$L_w = L_p + 20\log_{10}(r) + 10\log_{10}\left(\frac{4\pi p_{rms,ref}^2}{\rho c W_{ref}}\right)$$

$$L_p = L_w - 20\log_{10}(r) - 10\log_{10}\left(\frac{4\pi p_{rms,ref}^2}{\rho c W_{ref}}\right)$$

The outcome of Equation (2–26) yields several insights. First, the sound pressure level is directly proportional to the sound power level. This implies that the louder the noise emitted at the source, the louder the noise perceived at the receptor. Further, the sound pressure level is inversely related to the distance from the source, i.e., as the distance between the noise source and receptor increases, the loudness of the sound perceived at the receptor falls.

Another formulation of Equation (2–26) is to consider two receptors of distance r_1 and r_2 from a noise source (Bies & Hansen 2009). The sound pressure levels experienced by these two receptors are L_{p1} and L_{p2} respectively. Since the noise sound, acoustic medium, reference power, and pressure are the same for the two receptors, Equation (2–26) can be simplified to:

$$L_{p1} - L_{p2} = 20\log_{10}\left(\frac{r_2}{r_1}\right) \qquad (2–27)$$

Equation (2–27) also illustrates the inverse square law relationship, which states that sound level decay by 6dB per doubling of distance from a point source (since $20\log_{10}(2) \approx$ 6dB).

The results from Equation (2–26) illustrate the relationship between sound pressure levels, sound power levels, and distance for a non-directional spherical emitter of noise through a lossless medium. In reality, the source may be directional, i.e., there is an uneven distribution of the sound intensity as a function of direction (Beranek 1986). The medium that noise passes through may also absorb energy from the sound wave (Sutherland et al. 1974). For example, air could dissipate sound energy through friction between the air molecules as well as by molecules absorbing the sound energy and then re-radiating the sound at a later instant. The sound could also pass through noise barriers which seek to lower the loudness of the sound (Maekawa 1968). Hence, Equation (2–26) can be rewritten to take into account these factors:

$$L_p = L_w - 20\log_{10}(r) - 10\log_{10}\left(\frac{4\pi p_{rms,ref}^2}{\rho c W_{ref}}\right) + DI - A_{abs} - A_E \qquad (2–28)$$

where DI is the directivity index, which is a function describing the difference between the actual sound pressure in each direction and the sound pressure from a non-directional point source with the same acoustic power. A_{abs} is a function describing the absorption from the air. A_E is excess attenuation, which is the total attenuation in addition to the attenuation due to geometry and atmospheric absorption.

Consequently, to describe the transfer function, $\varphi(\cdot)$, introduced in Section 2.1, it is possible to use Equation (2–28). Equation (2–28) provides insight into the key factors which affect the transfer function. First, lower levels L_w will lead to lower levels of L_p, indicating that source control of noise will reduce the sound power level at the source which, in turn, reduces the sound pressure level at the receptor.

Second, an increase in the distance between the noise source and the receptor will reduce loudness at the receptor. Hence, zoning of activities, which physically separates noise sources and receptors, may reduce the loudness of sounds perceived at the receptor.

Third, path control of noise seeks to increase A_E, which also decreases the sound pressure level at the receptor (Maekawa 1968).

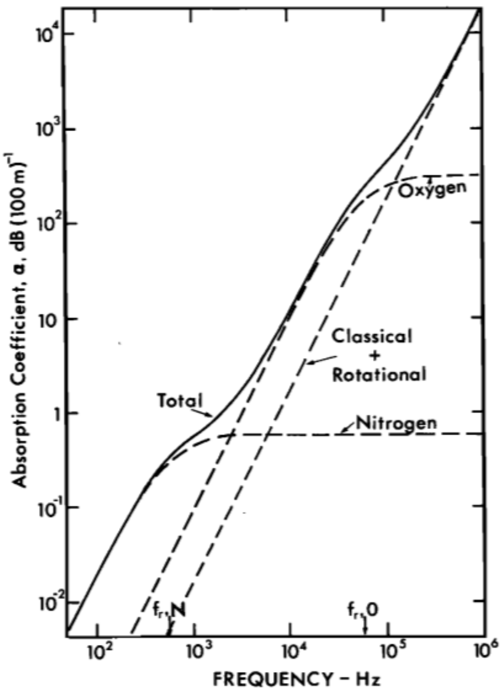
Fourth, air absorption, A_{abs}, reduces the loudness of noise as it travels through the air. The effect of air absorption is defined to be:

$$A_{abs} = \frac{\alpha r}{100} \tag{2–29}$$

where α is the absorption coefficient measured in dB per 100m and r is measured in metres.

Piercy, Embleton & Sutherland (1977) found that the absorption coefficient is dependent on the frequency of the noise. Absorption tends to be higher for higher frequency noise and as the distance between the noise source and receptor increases, the noise tends to have lower frequencies, since higher frequencies would be absorbed by the air molecules. Piercy, Embleton & Sutherland analysed laboratory and field measurements of noise over a wide range of frequencies and estimated that the relationship between the absorption coefficient, measured in dB per 100m change in distance between source and receptor, and frequency is described by Figure 2-4. The researchers found that loudness decreased by less than 0.01dB for every 100m increase in distance if the frequency of the noise was less than 100Hz, compared to more than 100dB decrease if the frequency was more than 10kHz. Bass, Sutherland & Zuckerwar (1990) extended the study by Piercy, Embleton & Sutherland to take into account the effect of humidity on the absorption coefficient.

Figure 2-4 Predicted atmospheric absorption at a pressure of one atmosphere, temperature of 20°C and relative humidity of 70%



Source: Piercy, Embleton & Sutherland 1977

In practice, solutions to Equation (2–28) may be difficult to estimate, given the large number of parameters and the complex functional forms of DI, A_{abs}, and A_E. The complexity of Equation (2–28) motivates the use of rule-of-thumb estimates of the transfer function, such as the inverse square law relationship described in Equation (2–27). The inverse square law relationship is commonly used by policy-makers when explaining noise regulations to the public (NSW-EPA 2013).

2.5.3 Aggregation of noise from multiple sources

Noise from multiple sources can be classified into coherent and incoherent sources. Coherent sources of noise have the same frequency, while incoherent noise sources have different frequencies and random phase relations. Noise from multiple construction and road sources are incoherent as they have different frequencies and have random phase relations. When sources of noise are incoherent, the total energy from the different sources is the sum of the energy from each source (Lord et al. 1980). Specifically, the total sound energy incident on a unit surface is:

$$I = \sum_{j=1}^{J} I_j \tag{2–30}$$

where I_j is the intensity due to source j.

Since the intensity is proportional to the square of pressure (see Equation (2–16)), Equation (2–30) can be rewritten as:

$$p_{rms}^2 = \sum_{j=1}^{J} p_{rms,j}^2 \tag{2–31}$$

where $p_{rms,j}^2$ is the root mean squared pressure due to source j.

Substituting (2–31) into the definition of the sound pressure level yields:

$$\begin{aligned} L_p &= 10 \log_{10} \left(\sum_{j=1}^{J} \frac{p_{rms,j}^2}{p_{rms,ref,j}^2} \right) \\ &= 10 \log_{10} \left(\sum_{j=1}^{J} 10^{\frac{L_{p,j}}{10}} \right) \end{aligned} \tag{2–32}$$

where $L_{p,j}$ is the sound pressure level caused by source j.

Equation (2–32) is the noise aggregating function, $\sigma(\cdot)$, introduced in Section 2.1. Equation (2–32) indicates that the sound pressure level from multiple sources of noise is not linearly additive. For instance, two noise sources producing 50dB of noise each will not result in an ambient noise level of 100dB. Rather, the resulting ambient noise level is 53dB.

2.6 Conclusion

Given the research motivation presented in Section 1.3, this chapter began with a discussion on noise pollution and its control in Singapore. The discussion indicates that control of construction and road noise is challenging, given the high number of construction sites and roads that are near residential areas. This finding supports the motivation provided in Section 1.3 to examine policies to reduce construction and road noise in an urban setting.

To examine changes to noise abatement policies, a conceptual framework to conduct cost-benefit analysis of such policies was introduced. Since policy-makers do not know whether a proposed change to noise abatement policy results in potential Pareto improvements *a priori*, cost-benefit analysis provides information on the welfare change attributable to policy changes. Accounting for the welfare change attributable to public provision of noise abatement ensures that these result in a potential Pareto improvement.

To conduct the cost-benefit analysis, information on the marginal benefits and marginal costs of abating noise pollution is required. Further, the noise transfer function and the noise aggregation function are arguments in the marginal benefits function as noise is transferred from the source to the receptor and each receptor may be exposed to multiple noise sources. A change to noise abatement policy results in a potential Pareto improvement if the benefits arising from the public provision of noise abatement outweigh the costs of providing this measure.

The literature was reviewed to understand previous research on the marginal benefits and costs of noise abatement as well as the noise transfer and aggregation functions. The former two functions are informed by the economic valuation literature while information on the latter two are derived from acoustic engineering literature.

The literature review found that a key gap in the literature involved estimation of the marginal benefits of noise abatement. Markets do not exist for residents to express their preferences for publicly-provided noise abatement. Consequently, non-market valuation techniques are required to estimate the marginal benefits of policies that reduce the level of noise. The two main non-market valuation approaches are revealed preference studies and stated preference studies. In order to estimate marginal benefits, revealed preference studies require data on respondents' demography and prior private investment into noise abatement, and, with the exception of specific countries, such information is not available publicly. Stated preference studies have also been conducted to estimate the marginal benefits of publicly-provided noise abatement. Previous stated preference studies described changes to noise levels textually.

Describing changes to noise levels textually is challenging. Unlike other environmental pollutants, noise pollution is measured in decibels, which is scaled logarithmically. Further, perceived loudness does not vary linearly with increased decibels. Consequently, a wide range of text-based descriptions has been developed to communicate changes in noise levels to respondents. However, no previous study has applied the techniques from audiology to estimate the preference for noise abatement by playing noise recordings to respondents.

This gap in the literature presents an opportunity to improve the methodology of stated preference surveys estimating the willingness-to-pay for public provision of noise abatement.

Specifically, an audio-based stated preference survey questionnaire can be designed to estimate the willingness-to-pay for noise abatement. In a text-based survey, respondents need to read, understand, and interpret the descriptions provided in the questionnaire. However, if respondents were presented with audio recordings of different noise levels, they can directly perceive changes to the noise level and do not need to read and understand textual descriptions of noise levels. Since understanding the information provided in a stated preference questionnaire is necessary to ensure that respondents reveal their true preferences, an audio-based survey questionnaire may provide more accurate estimates of the marginal benefits of noise abatement.

The literature review indicates that residents' preferences for noise abatement may be heterogeneous. First, prior spending on noise abatement measures can potentially affect the preference for public provision of noise abatement. Privately-provided noise abatement can substitute publicly-provided measures. However, the relationship between existing private provision of noise abatement and the willingness-to-pay publicly-provided noise abatement is an empirical question that has not been examined by previous studies.

Second, health status can affect the willingness-to-pay for health risk mitigation measures. Consequently, individuals' hearing sensitivity may affect their willingness-to-pay to reduce noise abatement and protect their hearing by reducing noise levels. However, no previous study directly measured the hearing sensitivity of respondents and the relationship between hearing sensitivity and willingness-to-pay for publicly-provided noise abatement.

Finally, some previous stated preference studies have used different locations to describe changes in noise levels to respondents, suggesting that ambient noise levels affect preferences for noise abatement. Further, revealed preference studies used variation in the location of properties to estimate the effect of noise levels on property prices. Hence, another potential source of heterogeneity is ambient levels of noise, proxied by the distance between the noise source and respondents' home.

The next chapter presents a list of research questions in light of the gaps in the literature presented in this chapter. These research questions are constructed based on the challenge of explaining changes to noise level with a text-based questionnaire and to understand the heterogeneous preferences for noise abatement.

Chapter 3: Research Questions

This chapter presents six research questions that the research conducted in this thesis seeks to address. The research questions were constructed based on the research motivation presented in Section 1.3 and the conceptual framework to conduct a cost-benefit analysis of noise abatement policy introduced in Chapter 2.

To conduct a cost-benefit analysis of publicly-provided noise abatement, information on the marginal benefits and marginal costs functions of noise abatement is required. Further, the noise transfer and noise aggregating functions are arguments in the marginal benefits function. The literature review presented in Chapter 2 found that a number of questions remain unanswered in previous studies estimating the marginal benefits of noise abatement. These questions are framed into the six research questions presented in this chapter.

3.1 Research Question 1: What is the willingness-to-pay for public provision of construction noise abatement?

Previous stated preference estimating the marginal benefits of noise abatement described changes to noise levels textually. Describing changes to noise levels textually is challenging as noise is measured on the decibel scale that is not readily understandable. Consequently, a wide range of textual descriptions has been developed to communicate changes to noise levels to the respondents. These surveys require respondents to read, understand, and interpret the descriptions provided in the questionnaire.

As stated preference surveys can only elicit the true preferences of respondents if they fully understand the information provided in the questionnaire, an inaccurate estimate of the willingness-to-pay for noise abatement may be obtained if respondents did not understand the survey questionnaire. Hence, the design of a readily understandable questionnaire is crucial, albeit challenging.

To overcome the challenge of designing an understandable survey questionnaire, a survey was designed to present respondents with audio recordings of construction noise to describe the changes in construction noise levels. Presenting respondents with audio recordings enable them to hear the change in noise levels when answering the survey. This approach draws on studies in audiology, which measure the physiological and psychological response of subjects to noise exposure.

Contributions to the literature from research undertaken to answer this research question are two-fold. First, the innovative use of audio recordings to describe noise levels has not been used in previous stated preference studies. The audio-based representation of noise levels enables respondents to directly perceive the noise levels associated with each hypothetical scenario in the survey, overcoming the challenge of describing changes to noise levels textually.

Second, previous studies have not estimated the marginal benefits associated with public provision of construction noise abatement. The only study that examined the externalities associated with construction noise abatement was Agarwal et al. (2016), which used a revealed preference approach. Since construction noise is prevalent in urban centres, estimating the marginal benefits of construction noise abatement can inform future noise abatement policies in Singapore and other urban centres.

3.2 Research Question 2: What is the willingness-to-pay for public provision of road noise abatement?

The second key source of noise pollution in urban centres is noise from the road network. As discussed in Research Question 1, previous stated preference studies estimating the marginal benefits of road noise abatement described changes to the noise levels textually. To overcome the challenges with designing a readily understandable text-based questionnaire, an audio-based questionnaire was designed to estimate the willingness-to-pay for road noise abatement. The audio-based survey described changes to road noise levels with recorded road noise.

The research undertaken to answer this question has a methodological and policy contribution. The methodological contribution arises from the novel design of the audio-based survey questionnaire. The road noise survey conducted in this thesis is the first stated preference survey that described changes to road noise levels with audio recordings instead of textual descriptions. Since respondents are able to hear the noise levels, they do not need to read and interpret textual descriptions of noise abatement.

The results from the road noise survey inform the formulation of road noise policy. While previous stated preference studies estimating the value of road noise abatement has been conducted, none of these studies has been conducted in Singapore. Hence, the marginal benefits of road noise abatement obtained this survey can inform future policies to publicly provide road noise in Singapore.

3.3 Research Question 3: Does the use of audio recordings in a choice set improve respondents' understanding of the changes to the noise level?

Estimated willingness-to-pay for noise abatement from a text- and audio-based survey may be different. It is not clear *a priori* whether a text- or audio-based survey will yield a higher willingness-to-pay for noise abatement. Further, it is not known *a priori* whether respondents understand the information provided in a text-based questionnaire. Finally, the relationship between respondents' understanding of survey questionnaires and willingness-to-pay for noise abatement is not known *ex ante*.

These issues motivate the third research question. In response to this question, a sub-sample of the construction noise respondents are presented with a text-based survey questionnaire instead of an audio-based questionnaire. To eliminate sources of heterogeneity between the two surveys, both surveys use the same valuation questions, except that the text-based questionnaire described changes to noise levels textually. The survey methods for both surveys were also identical.[22] The text-based survey also included ancillary questions to test respondents' understanding of the textual description of changes to noise levels.

Comparison of the results from the text- and audio-based questionnaire provide an estimate of the difference in willingness-to-pay from both surveys. Further, results from the test questions enable analysis of the effect of understanding on willingness-to-pay for noise abatement.

Results from the analysis conducted to answer this research question have two contributions. First, the results provide a channel to explain differences in willingness-to-pay obtained when respondents are presented with different representations of hypothetical scenarios in stated preference surveys. Specifically, the research conducted in the thesis explores the effect of understanding on willingness-to-pay for changes to policies. The direction of bias caused by a lack of understanding is not known, respondents may under- or

[22] Specifically, both survey were conducted using tablets on the door steps of respondents' homes. See Section 4.3 for a discussion on the implementation of both surveys.

over-state their willingness-to-pay if they do not understand the survey questionnaire. Hence, this study seeks to shed light on the direction of bias.

Second, the results contribute to the design of stated preference studies estimating the marginal benefits of noise abatement. Since previous stated preference studies described changes to noise levels textually, respondents may not fully understand the descriptions provided in these surveys. By comparison, when respondents are presented with audio-recordings, they do not need to understand textual descriptions of changes to noise levels. Hence, the results provide insights into whether previous studies may have estimated the marginal benefits of noise abatement incorrectly.

3.4 Research Question 4: How does prior investment into noise abatement affect the marginal benefits of public-provided noise abatement?

Noise pollution is a local pollutant that can be privately mitigated. Examples of private abatement measures include the installation of thicker curtains, double glazed windows, or the purchase of headphones. Consequently, publicly provision of noise abatement is provided in addition to existing privately installed noise abatement measures. However, previous studies have not estimated the relationship between private and public provision of noise abatement. The effect of prior private spending on noise abatement on public provision of noise abatement is ambiguous. On the one hand, private and public spending on noise abatement are substitutes, so increased prior private spending on noise abatement may reduce demand for publicly-provided measures. On the other hand, residents who are more annoyed by noise pollution may selectively invest in private noise abatement measures. Since these residents are especially annoyed by noise pollution, they may have a higher willingness-to-pay for publicly-provided noise abatement as compared to other residents.

In this thesis, the relationship between prior private spending on willingness-to-pay for noise abatement is estimated. Prior private spending proxies for existing privately-provided noise abatement measures. The relationship between privately-provided noise abatement and publicly-provided noise abatement can inform the formulation of noise abatement policies. For instance, if private and public provision of noise abatement is negatively correlated, publicly-provided noise abatement can potentially yield higher benefits in new estates where all residents have not privately invested in noise abatement measures.

3.5 Research Question 5: Does hearing sensitivity affect the estimated marginal benefits of noise abatement?

Individuals' health status can affect their willingness-to-pay for health risk mitigation. Specific to noise pollution, individuals' hearing sensitivity can potentially affect their willingness-to-pay for publicly-provided noise abatement. For example, individuals with higher hearing sensitivity may be more annoyed by noise pollution and have an increased willingness-to-pay for noise abatement. However, previous studies have not studied the effect of hearing sensitivity on willingness-to-pay for noise abatement, partly because these studies could not measure the hearing sensitivity of respondents directly.

In the surveys conducted in this thesis, hearing sensitivity is measured with a hearing acuity test, where respondents are asked to identify the quietest pure-tone noise they can perceive (British Society of Audiology 2011). Observation of an individual's hearing sensitivity enables estimation of the relationship between hearing sensitivity and willingness-to-pay for noise abatement.

The results from this study contribute to the health economics literature since few studies have been conducted to empirically estimate the relationship between health status and willingness-to-pay for health risk mitigation. Further, no study has examined the effect of hearing sensitivity on willingness-to-pay for noise abatement. The results from this study can also inform the design of noise abatement policies near noise sensitive areas such as schools and hospitals.

3.6 Research Question 6: Does exposure to noise affect respondents' willingness-to-pay for noise abatement?

An individual's prior experience with construction or road noise may influence the individual's preferences for noise abatement. On the one hand, increased noise levels can potentially lead to respondents becoming more annoyed with noise, in turn leading to a greater preference for noise abatement. On the other hand, residents may become acclimatised to the increased noise levels, leading to a concomitant fall in willingness-to-pay for noise abatement. As Singapore does not have administratively collected data on noise levels, the distance between the residence of a respondent and the nearest construction site or major road was used as a proxy for levels of noise from these noise sources.

Estimating the effect of the distance between respondents' residence and the nearest noise source on willingness-to-pay for noise abatement provides insight into how ambient noise levels affect preferences for noise abatement.

3.7 Conclusion

Six research questions were posed in this chapter. These research questions were motivated by the need to estimate the marginal benefits of noise abatement in order to inform the design of noise abatement policies. The research questions were constructed in light of unexplored questions in the literature.

Answers to these research question involve the estimation of residents' willingness-to-pay for construction noise abatement. Since the survey is contextualised to Singapore, the willingness-to-pay is estimated in Singapore dollars[23] and unless otherwise indicated, dollar values in the remainder of the thesis refer to Singapore dollars.

The remainder of the thesis addresses the questions presented in this chapter. In the next part of the thesis (comprising Chapters 4 to 6), the design of the survey questionnaire is presented. Specific to the next chapter, the theoretical framework of the research conducted to answer the research questions is presented, followed by a discussion of the research design and implementation.

[23] As of June 2019, S$1 is equivalent to US$0.74, €0.65, and AU$1.06 (Monetary Authority of Singapore 2019b).

Chapter 4: Eliciting the Willingness-to-pay for Noise Abatement

This chapter is the first of three chapters discussing the design of the surveys conducted to answer the research questions presented in Chapter 3. These surveys estimate the marginal benefits of construction and road noise abatement in order to inform cost-benefit analysis of future policies to control noise from these sources.

To provide a basis of the surveys conducted in this thesis, this chapter begins with an introduction to the random utility model in Section 4.1. The model serves as a framework to understand the choices made by individuals when they choose between different options. Section 4.2 presents the research design, followed by a discussion of the various phases of the survey in Section 4.3. The design of the survey questionnaire is an iterative process, where each phase of the survey informs subsequent phases. This design process is described in Section 4.4.

4.1 Theoretical foundations of individual utility and choice

A choice modelling study seeks an understanding of the preferences of a non-marketed good or service. In a choice modelling survey, a set of alternatives is presented to respondents, who are asked to choose the most-preferred alternative. Lancaster's Theory of Demand (1966) provides the framework for the design of the alternatives in the survey questionnaire. A set of attribute describes the alternatives and different levels of the attributes characterise each alternative. The analyst observes the choices made by the respondent and estimates the underlying utility of the respondent.

A commonly used model to describe individual choice is the random utility model introduced in McFadden (1974) (Scarpa & Rose 2008). The remainder of this section first introduces the random utility model before discussing the methods to estimate individual utility from the choices made by the respondent.

4.1.1 Random utility model

As discussed in Section 2.2.2, if the preferences of an individual are complete, transitive, continuous and monotonous, then the individual's preference ranking can be mapped to a real-valued utility function that assigns higher numerical values to preferred alternatives.

Using the notation from Section 2.2.2, suppose individual i chooses from K number of alternatives, each indexed k, then the individual's utility for alternative k is denoted u_{ik}.

When faced with a set of K number of alternatives, individuals will make choices based on their underlying preference ranking. Hence, if the individual chooses a specific alternative, k_a, when faced with K number of alternatives, then the individual reveals that she prefers k_a to all other alternatives in the choice situation. Concomitantly, the utility associated with k_a is the highest among all other alternatives, implying that:

$$u_{ik_a} \geq u_{ik_b}, \forall a \neq b \tag{4–1}$$

or, equivalently,

$$u_{ik_a} = \underset{K \in \{k_1, k_2, \dots, k_K\}}{\text{argmax}} \; u_{ik} \tag{4–2}$$

The random utility model provides the conceptual base for modelling the choices of individuals. An individual's preference for each alternative could be influenced by many factors. The factors affecting individual preferences could be broadly categorised into factors which can be observed by the analyst[24] and factors which cannot be observed by the analyst[25].

As such, the individual's utility, u_{ik}, is partitioned into an observed component, V_{ik} and an unobserved component, ε_{ik} (Hensher, Rose & Greene 2015). If the observed and unobserved components of utility is additively separable, the utility function can be written as[26]:

$$u_{ik} = V_{ik} + \varepsilon_{ik} \tag{4–3}$$

The observed component of utility can be modelled to be a function of the variables of the attributes which describe each alternative and the covariates describing the individual as well as a set of parameters to be estimated. Specifically, V_{ik} can be defined to be:

$$V_{ik} = f(Z_{iik}, \beta) \tag{4–4}$$

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[24] An example of an observable characteristic is the demography of the respondent (e.g., age and income of the respondent). The analyst could design the survey questionnaire to include questions on the demography of the respondent. Hence, these characteristics of the respondent would be observable to the analyst.

[25] Examples of an unobservable characteristic are the background level of noise and the mood of the individual. The analyst may not have the equipment to record the background level of noise when the respondent is completing the survey and this factor would be an unobserved characteristic of the respondent. Similarly, the analyst may not be able to quantify the mood of respondents when they are answering the survey questionnaire.

[26] Similar to all utility functions, the utility function described in Equation (4–3) is ordinal and any positive monotonic transformation of this function will result in an equivalent ranking of preferences. Consequently, scaling Equation (4–3) by a positive real number, $\lambda \in \mathbb{R}^+$, yields $\lambda u_{ik} = \lambda V_{ik} + \lambda \varepsilon_{ik}$. For the remainder of this section, λ is scaled to one.

where $Z_{i\mathbb{i}k}$ is a vector of $\mathbb{i}$ attributes describing alternative k. β is a set of parameters to be estimated by the analyst and β assigns weights to each attribute in $Z_{i\mathbb{i}k}$.

To model the unobserved component of utility it is necessary to make assumptions about how these preferences are formed. A common assumption is that for each alternative, the unobserved component of utility, ε_{ik}, is randomly distributed with some density over individuals n and choice situation s (Hensher, Rose & Greene 2015). This probability density function is denoted $f(\varepsilon_{ik})$ and assumptions about the functional form of the probability density function leads to different econometric models.

Suppose that the probability density function, $f(\varepsilon_{ik})$, exists, then it is possible to reframe Equation (4–1) and Equation (4–2) in probabilistic terms. Define P_{ik_a} to be the probability that alternative k_a yields the highest level of utility among K number of alternatives, i.e., the probability that alternative k_a is chosen among K alternatives, then,

$$P_{ik_a} = \Pr\left(u_{ik_a} > u_{ik_b}\right), \forall a \neq b \tag{4–5}$$

substituting Equation (4–3) yields:

$$P_{ik_a} = \Pr\left(V_{ik_a} + \varepsilon_{ik_a} > V_{ik_b} + \varepsilon_{ik_b}\right), \forall a \neq b \tag{4–6}$$

Equation (4–5) and (4–6) implies that the utilities for each choice situation, u_{ik_a}, are linked to other utilities by the probability function (Hensher, Rose & Greene 2015). Since P_{ik_a} is a probability, for all alternatives P_{ik_a} is bounded by 0 and 1. In addition, choosing k_a precludes the choice of k_b, $\forall b \neq a$. Assuming further that the set of alternatives, K, is exhaustive, then all the probabilities must sum to one, i.e., $\sum_{k=1}^{K} P_{ik} = 1$. Consequently, *ceteris paribus*, an increase in u_{ik_a} implies that P_{ik_a} will increase, i.e., it is more likely that the respondent will choose k_a. Furthermore, P_{ik_b}, $\forall b \neq a$ will fall, i.e., it is less likely that the respondent will choose k_b, $\forall b \neq a$.

4.1.2 Conditional logit model

While different probability density functions can be used to describe $f(\varepsilon_{ik})$[27], a commonly used function is the extreme value type one (EV1) distribution, i.e., a Gumbel

[27] Another candidate distribution function is the normal probability distribution function. However, there is no closed form solution to estimate the probabilities that a particular alternative will be chosen. Consequently, estimating the probabilities is computationally intensive, which has led to the popularity of the use of the Gumbel distribution (Hensher, Rose & Greene 2015).

distribution (Train 2003). The probability distribution function of a standard Gumbel distribution is (Gumbel 1954):

$$f(\varepsilon_{ik}) = e^{-(\varepsilon_{ik}+e^{-\varepsilon_{ik}})} \tag{4–7}$$

with a corresponding cumulative distribution of:

$$F(\varepsilon_{ik}) = e^{-e^{-\varepsilon_{ik}}} \tag{4–8}$$

McFadden (1974) showed that if $f(\varepsilon_{ik})$ is described by the standard Gumbel distribution, where ε_{nsj} is independently and identically distributed, with a variance of $\frac{\pi^2}{6}$, then the probability that j_a is chosen can be described by the logistic function:

$$P_{ik_a} = \frac{e^{V_{ik}}}{\sum_{k=1}^{K} e^{V_{ik}}}, \forall k_a \in K \tag{4–9}$$

Recall from Equation (4–4) that the observed component of utility, V_{ik}, is a function of $\mathbb{i}$ attributes describing alternative k, $Z_{i\mathbb{i}k}$ and a set of parameters, β. If V_{ik} is described by a linear combination of $Z_{i\mathbb{i}k}$ and β, then V_{ik} can be defined as:

$$V_{ik} = \sum_{\mathbb{i}=1}^{\mathbb{I}} \beta_{\mathbb{i}} Z_{i\mathbb{i}k} \tag{4–10}$$

Substituting Equation (4–10) into Equation (4–9) yields:

$$P_{nsj_a} = \frac{e^{\sum_{\mathbb{i}=1}^{\mathbb{I}} \beta_{\mathbb{i}} Z_{i\mathbb{i}k}}}{\sum_{k=1}^{K} e^{\sum_{\mathbb{i}=1}^{\mathbb{I}} \beta_{\mathbb{i}} Z_{i\mathbb{i}k}}}, \forall j_a \in J \tag{4–11}$$

Equation (4–11) also reframes the interpretation of the respondent’s observed component of utility as an underlying latent variable and the logistic function as a link function. The observed component of utility is a continuous variable which can take the value of any real number, which is mapped to the probability space (bounded by 0 and 1) by the logistic function. Hence, the analyst is able to estimate the utility function of the respondent by observing which alternatives are chosen by the respondent when the respondent encounters a given choice situation.

4.1.3 Limitations of the conditional logit model and alternative models

While the conditional logit model provides a closed-form solution to understanding the utility function of the respondent, the assumption that the unobserved component of utility is independently and identically distributed is restrictive (Train 2003). This assumption implies that the unobserved component of utility is not related to the unobserved component of another alternative. Consequently, alternatives to the conditional logit model have been developed to relax this assumption.

One possible specification which relaxes the restrictive assumptions that the unobserved component of utility is independently and identically distributed is the random parameter logit model (Hensher, Rose & Greene 2015). Similar to the conditional logit model, the probability that an alternative, j_a, is chosen when individual n is faced with choice situation s, is defined by Equation (4–10). However, unlike the conditional logit model, the random parameter logit model assumes that at least some of the parameters in the model are randomly distributed over the population such that:

$$V_{ik} = \sum_{\mathbb{i}=1}^{\mathbb{I}} \beta_{i\mathbb{i}} Z_{i\mathbb{i}k} \tag{4–12}$$

where $\beta_{i\mathbb{i}}$ is described by a constant, $\overline{\beta}_{\mathbb{i}}$, a vector of observable characteristics of respondent, z_i, and a vector of unobservable characteristics, $v_{i\mathbb{i}}$. If these terms are linearly separable, then, $\beta_{i\mathbb{i}}$ is defined as:

$$\beta_{i\mathbb{i}} = \overline{\beta}_{\mathbb{i}} + \Delta z_i + \Gamma v_{i\mathbb{i}} \tag{4–13}$$

where Δ and Γ are the parameters to be estimated.

Equation (4–13) indicates that the mixed logit model is a generalisation of the conditional logit model. Specifically, if $\Delta = 0$ and $\Gamma = 0$, then $\beta_{i\mathbb{i}} = \overline{\beta}_{\mathbb{i}}$ and Equation (4–12) is equivalent to Equation (4–10). This also implies that the analyst could model the observed characteristics of the respondents in order to control for potential correlation between the unobserved components of utility.

4.1.4 Welfare estimates

Recall from Section 2.2.2 that the willingness-to-pay for publicly-provided noise abatement corresponds to the compensating variation. Taking the total derivative of the utility function and setting the change in utility to be zero yields the marginal benefits associated with a change in attribute, $MB_i(Z_{\mathbb{i}ik})$, measured in dollar terms. This marginal benefits function is:

$$MB_i(Z_{\mathbb{i}ik}) = -\frac{\partial u_{ik} / \partial Z_{\mathbb{i}ik}}{\partial u_{ik} / \partial price_{ik}} \tag{4–14}$$

Since the observable component of utility described in Equation (4–12) is linear in the attributes, the partial derivative of the utility function with respect to changes in the levels of each attribute is the regression coefficient, $\beta_{\mathbb{i}}$. As such, the marginal benefits associated with the change in each attribute can be rewritten as:

$$MB_i(Z_{\mathbb{i}ik}) = -\frac{\beta_{\mathbb{i}}}{\beta_{cost}} \tag{4–15}$$

Since the marginal benefits described in Equation (4–15) is a function of the regression parameters, each of which is distributed around the mean described by some variance, the willingness-to-pay is also distributed around the point estimate. In order to estimate the variance of the marginal benefits, a variety of methods have been developed. Examples include the delta method, the Fieller method, and the Krinsky & Robb bootstrapping procedure (Hole 2007a; Krinsky & Robb 1986). Unlike the delta and Fieller methods, both of which assumes a normal distribution, the Krinsky & Robb method does not assume that the marginal benefits follow any distribution.

4.2 Research design

Section 4.1 presented the theoretical framework of the choice modelling study. A choice modelling study seeks an understanding of a respondent's preferences by observing which alternative is chosen by a respondent when she encounters a choice situation. The alternatives are designed systematically and characterised by a fixed set of attributes with each alternative described by a different combination of levels.

The remainder of this section describes the research design to answer the research questions from Chapter 3. The researcher conducted a series of choice modelling surveys to collect primary data on respondents' preferences for noise abatement. Two audio-based surveys were conducted to address Research Questions (1) and (2), namely a survey estimating the marginal benefits of construction noise abatement and a survey estimating the marginal benefits of road noise abatement. Both these survey questionnaires described changes to noise levels with audio recordings. Other attributes in these survey questionnaires were presented textually. Respondents chose their preferred options and analysis of the choices made by respondents reveal the marginal benefits of public provision of construction and road noise abatement.

The researcher addressed Research Question (3) by splitting the main field survey for construction noise into two sub-samples. The first sub-sample was presented with the audio-based survey described above. The second sub-sample presented respondents with a text-based survey questionnaire. The text-based questionnaire communicated changes to noise levels with textually. To ensure that the valuation obtained from both sub-samples differed solely due to the change in how noise was represented, all other aspects of the valuation questions were the same. Specifically, the scenario presented to respondents as well as the experimental design of the choice sets were the same. Both surveys were conducted face-to-face at the respondents' doorstep using the same electronic tablets. The similar survey design and implementation enable the effects of different representations of noise to be isolated.

Ancillary questions were included to test respondents' understanding of the textual descriptions of noise levels in the text-based questionnaire. These test questions were true/false questions that sought to ascertain respondents' understanding of the information provided as well as their prior knowledge about how noise is measured. Responses to these questions enable examination of the potential heterogeneous effect of understanding the information provided in the survey questionnaire on willingness-to-pay for noise abatement.

To estimate the potential heterogeneous preferences for publicly-provided noise abatement conditioned on private expenditures to abate noise as outlined in Research Question (4), the respondents' prior investment into noise abatement measures was asked. Specifically, respondents were asked how much they had privately invested in noise abatement. Details on the design of this question are provided in Section 5.9.1. The private investment into noise abatement is taken as a proxy for the level of reduction in noise abatement in decibels. The heterogeneous effect of privately-provided investment into noise abatement on willingness-to-pay for publicly-provided noise abatement was estimated.

The researcher designed a hearing acuity test to estimate the respondent's quietest perceivable test-tone. Design of hearing acuity test is discussed in Section 5.9.2. The quietest perceivable test-tone proxies for respondents' hearing sensitivity. Results from the hearing acuity test provide insights into the effect of hearing sensitivity on preferences for noise abatement posed in Research Question (5). The heterogeneous effect of hearing acuity on willingness-to-pay for noise abatement is then estimated.

Research Question (6) was addressed with the inclusion of questions about respondents' prior experience of living near construction sites and major roads. Respondents were also asked about the annoyance caused by living near these noise sources, and to provide their postal code numbers when answering the survey. The postal code was geocoded with Singapore's OneMap geospatial service, and the distance between each resident and the closest construction site and road was estimated with the geospatial software QGIS. The heterogeneous effect of distance between respondents' residences and noise sources was estimated.

4.3 Overview of survey implementation

Since the survey involves primary data collection and respondents of the survey would be exposed to recorded sounds that might potentially be unpleasant, the protocols for the research conducted in this thesis were submitted for approval by the ANU Human Research Ethics Committee (Protocol 2017/64). Approval was obtained before commencing any research activity. The ethical consideration in the design and implementation of the various phases of the research are detailed in Chapters 5 and 6.

In all phases of the survey, the questionnaire presented to the respondents was an electronic questionnaire preloaded onto a tablet. Further, for the survey questionnaire that presented recordings of noise to respondents, a headphone was connected to the tablet. The tablets and headphones used for all surveys were the Samsung Galaxy Tab 5 and Audio Technica M40x respectively.[28] The make and model of the tablets and headphones were standardised in order to ensure that the loudness of the sounds presented to respondents was not affected by differences in the survey equipment.

The need to standardise survey equipment precluded the use of an internet survey, under which respondents could complete the survey on a website with their own computer or tablet. An internet survey would require respondents to hear the audio recordings in the survey via different sound reproduction devices (e.g., headphones, earphones, speakers). Respondents would also have different computer hardware (e.g., different soundcards) and software (e.g., different operating systems) on their computers. Different hardware, in turn, leads to different loudness perceived by each respondent. Hence, it would not be possible to standardise the loudness of the audio clip across all respondents if an internet survey was conducted.

Given the large number of survey respondents and the need for face-to-face surveys with a standardised set of survey equipment, MediaCorp Research Company (MRC) was contracted to conduct the survey on behalf of the researchers. MRC is a subsidiary of one of Singapore's largest media companies which has previously conducted surveys for various

[28] Details on the choice of the headphones are provided in Chapter 7.

government agencies as well as private companies. Further, MRC was on a panel of survey companies recommended by Singapore's Ministry of Communications and Information[29].

The researcher conducted the construction noise survey in three phases, namely, focus group discussions, a laboratory survey as well as a door-to-door survey. A total of four focus group discussions were conducted to pre-test the construction noise survey questionnaire. The laboratory survey comprised of two phases, a pilot survey with a sample size of 40 and the full survey with a sample size of 160.[30] The door-to-door survey also comprised of two phases, a pilot phase with a sample size of 200 and a full survey with a sample size of 1,000.[31] The door-to-door survey further consisted of two sub-samples. The first sub-sample consisted of 800 respondents and they were presented with a survey questionnaire describing changes in noise levels with recorded noise. The second sub-sample comprised the remaining 200 respondents who were presented with a traditional survey questionnaire that described changes in noise levels textually. Analysis of the results from the laboratory survey and the two sub-samples of the door-to-door survey provided insights into how different survey modes and presentation methods affect estimated marginal benefits of construction noise abatement.

Both the focus group discussion and laboratory survey were conducted in a conference room at the survey company's premises.[32] Around ten to fifteen individuals participated in each session, which was facilitated by two staff from the survey company. The door-to-door surveys were conducted face-to-face by surveyors at the doorstep of each respondent's house. In Singapore, it is customary for short surveys to be completed at respondents' doorstep. Since the surveys designed in this thesis can be completed in less than 30min, the surveys were sufficiently short for most respondents to prefer completing the survey at the doorsteps of their homes. The survey protocols do not preclude respondents completing the survey in their homes, however, only a minority of respondents invited the surveyor into their homes.

The road noise survey was conducted over two phases, namely, the focus group discussions as well as a wide-scale door-to-door survey.[33] Two focus group discussions were

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[29] Based on internal correspondence with officers at the Ministry of the Environment and Water Resources.
[30] The participants for the laboratory survey were recruited from a representative panel of respondents from a survey company.
[31] This sampling frame was obtained from Singapore's Department of Statistics. Details on the design of the sampling frame is provided in Chapter 7.
[32] MRC's office is co-located with MediaCorp Singapore. The address of the office is 1 Stars Avenus, Singapore 138507.
[33] A similar laboratory survey was not conducted for road noise due to budgetary constraints. Specifically, MEWR provided funds amounting to S$200,000 for the construction noise survey, while LTA provided funds amounting to S$44,000 for the road noise survey. While LTA's funding was insufficient to conduct a laboratory survey, it

conducted to pre-test the road noise survey questionnaire. Similar to the construction noise survey, the door-to-door survey for road noise comprised of a pilot survey and a main survey which had a sample size of 100 and 500 respectively.[34]

Similar to the focus group discussions for construction noise, the road noise survey was conducted in a room at the survey company's premises. Around ten individuals participated in each discussion. The door-to-door surveys to estimate the marginal benefits of road noise abatement was conducted face-to-face by surveyors at the doorstep of each respondent's house.

4.4 Steps taken to design survey questionnaire

The steps taken to design the survey questionnaire are illustrated in Figures 4-1 and 4-2, while the timeline of the study was provided in Figure 4-3.

Figure 4-1 Steps taken to design the survey estimating the value of construction noise abatement

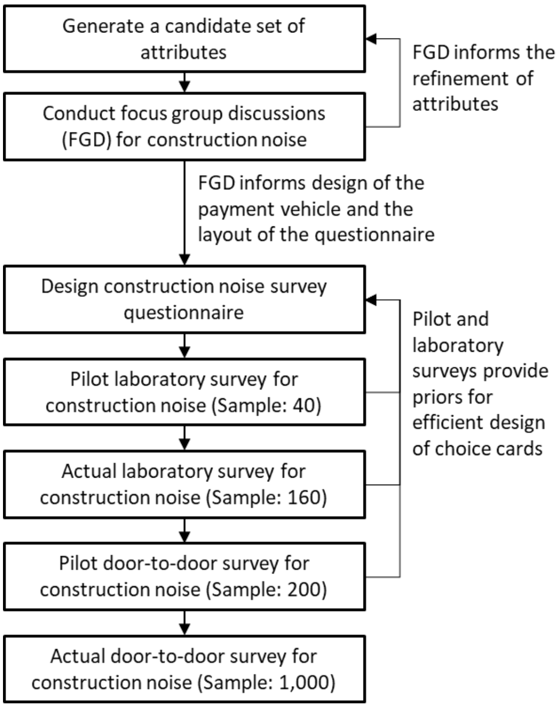
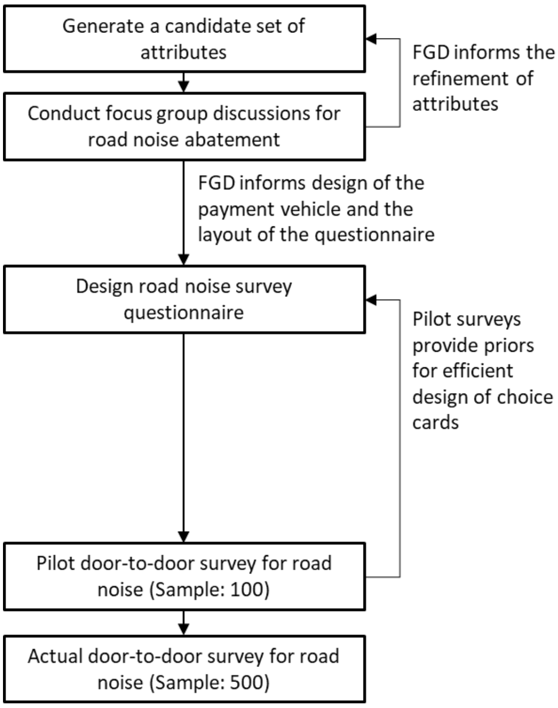


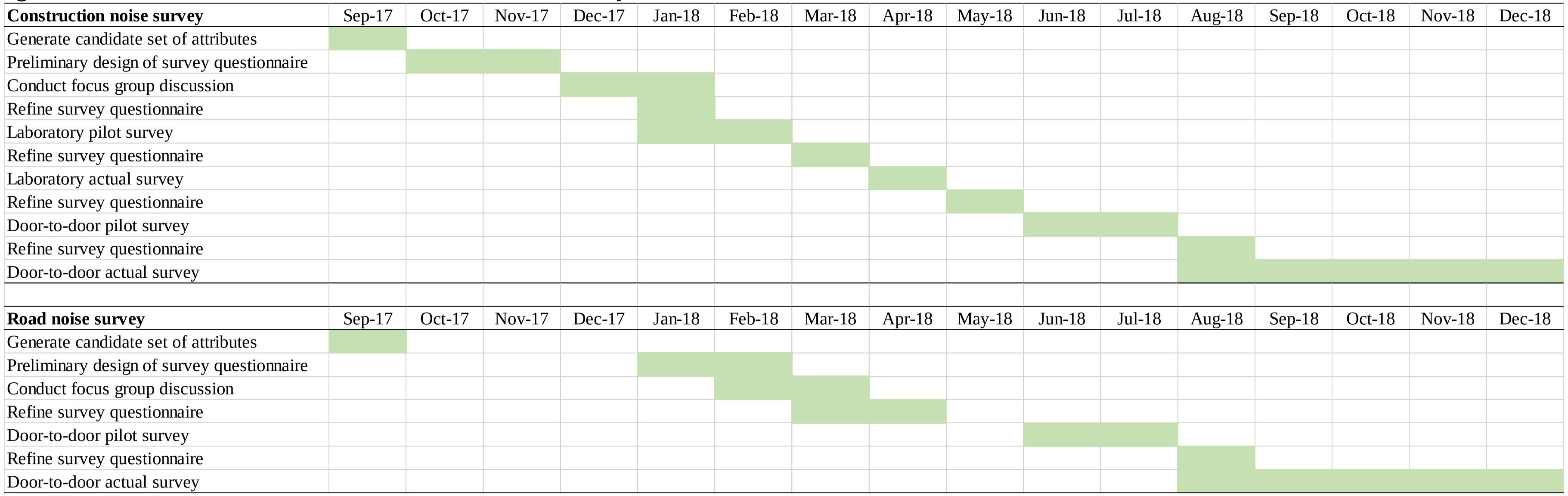
Figure 4-2 Steps taken to design the survey estimating the value of road noise abatement



was sufficient to conduct two focus group discussions and a door-to-door survey with a sample size of 600. For the same reason, a survey with textual description of changes in road noise levels was not conducted for the road noise sample.

[34] This sampling frame was obtained from Singapore's Department of Statistics. Details on the design of the sampling frame is provided in Chapter 7.

Figure 4-3 Gantt chart of the construction and road noise surveys



Design of the survey questionnaire was an iterative process with each phase of the survey informing the design of the questionnaire. The design of both the construction noise and road noise survey questionnaires began with proposing a candidate set of attributes to describe the policy changes to reduce construction and road noise. The candidate list of attributes was determined based on several different sources. First, recordings of construction and road noise in Singapore were obtained. These recordings were then analysed to ascertain the characteristics of noise. Second, sources of annoyance arising from construction and road noise were obtained from discussions with policy-makers in the Singapore government. Government agencies involved in these discussions include policy and operational officers from the Ministry of the Environment and Water Resources (MEWR), the National Environment Agency (NEA) and the Land Transport Authority (LTA). The list of candidate attributes for construction and road noise abatement will be discussed in Section 5.6.

The Gantt chart in Figure 4-3 indicates that the next phase of the survey questionnaire design was staggered such that the preliminary design of the construction noise survey questionnaire was completed first. The focus group discussions for the construction noise survey were then conducted to refine the construction noise survey questionnaire. The aims of these discussions were two-fold. First, the discussions sought to refine the candidate list of attributes, by understanding whether the candidate list of attributes fully represents the concerns of the public. Second, the discussions sought to inform the design of the survey questionnaire. Specifically, the views of respondents on the appropriateness of the payment vehicle, the levels of the proposed attributes, as well as the descriptions of the policy context was sought. Further, since no previous choice modelling study has attempted to present respondents with recorded construction noise, the focus group design is provided feedback from participants on the design of the questionnaire. In total, four focus group discussions, with a sample size of around ten each, were conducted for the construction noise survey and two discussions were conducted for the road noise survey. The design and results of these discussions are presented in Chapter 6.

The outcomes of the focus group discussion informed both the refinement of the construction noise survey questionnaire as well as the preliminary design of the road noise survey questionnaire. In particular, feedback from the respondents on the layout of the questionnaire was incorporated into both the construction noise and the road noise survey questionnaires.

The next step in the design of the survey questionnaire for the construction noise survey was the pilot phase of the laboratory survey, followed by the main laboratory survey. The pilot survey was conducted as a separate phase in order to provide priors for the efficient design of the main laboratory survey.

The laboratory survey served three purposes. First, as discussed in Section 4.2, the laboratory survey enabled a comparison of the estimated marginal benefits of noise abatement when the survey was conducted in a controlled environment and the door-to-door survey. Analysis of the responses to the laboratory survey also provided insight into how the demographic details of the respondents affected their preferences. In particular, the survey measured the hearing acuity of the respondents, enabling the estimation of the effect of hearing acuity on willingness-to-pay. Second, the laboratory survey enabled troubleshooting of the technical aspects of the survey questionnaire. Unlike previous choice modelling surveys estimating the benefits of noise abatement, this survey presented recorded noise to respondents. Hence, conducting the survey was technically challenging and completing the survey questionnaire in a laboratory setting enabled the immediate troubleshooting of any technical difficulties. Finally, just as the pilot laboratory survey provided priors for the main laboratory survey, the estimates from the laboratory survey provided priors for the door-to-door survey. Details on how the priors were incorporated into the design of the questionnaire are provided in Section 6.4.4.

Concurrent with the laboratory surveys for the construction noise survey, the focus group discussions for the road noise survey were conducted. The focus group discussions for road noise had two goals: firstly, the focus group discussions sought to refine the candidate list of attributes for the road noise survey, and secondly, the discussions also informed the design of the survey questionnaire. Feedback was sought on the payment vehicle, the levels of the proposed attributes and the description of the policy context. The design and results of these discussions are presented in Chapter 6.

After the conclusion of the laboratory survey for the construction noise survey and the focus group discussions for the road noise survey, the survey questionnaires for both surveys were refined with the results from these phases. A pilot door-to-door survey was conducted, followed by the main survey. The results of the pilot surveys provided the priors for the main door-to-door survey. The final survey questionnaires provided to respondents will incorporate the feedback from all previous phases of the study, namely, the focus group discussions and the laboratory surveys. The final design of the survey questionnaire is presented in Chapter 6.

The door-to-door survey seeks to answer the research questions outlined in Chapter 3 by estimating the marginal benefits associated with construction and road noise abatement. The results of the door-to-door survey will also be compared to the laboratory survey to understand the effect of survey modes on the estimated marginal benefits of noise abatement. Analysis of the responses to the door-to-door survey will also provide insight into how the demography of the respondents, particularly their hearing acuity, affected estimates of the marginal benefits of noise abatement.

4.5 Conclusion

This chapter discussed the design of the survey questionnaires used to estimate the willingness-to-pay for construction and road noise abatement. An outline of the theoretical foundations of a choice modelling survey was presented. This theoretical foundation is underpinned by the random utility model. Methods to analyse this model was discussed.

The theoretical foundations provide a basis for the design of a choice modelling survey to answer the questions posed in Chapter 3. The key component of the research conducted in this thesis involved the design of the audio-based survey questionnaires to estimate the willingness-to-pay for public provision of construction and road noise abatement. These questionnaires presented respondents with audio recordings of construction and road noise and varied the loudness of these recordings in the choice set. In addition to the audio-based questionnaires, a text-based questionnaire was prepared to estimate the effect of different noise representation on willingness-to-pay for construction noise abatement.

The design of the audio-based survey questionnaires was novel as no previous research has used audio recordings to describe changes in noise levels. Design of the audio-based survey questionnaire was complex as noise recordings had to be incorporated into the survey questionnaire, precluding the use of pre-programmed survey software. Consequently, the surveys were conducted in phases and each phase informed the design of subsequent phases. This iterative design process enabled the refinement and troubleshooting of the survey questionnaire. The next chapter discusses the first step of the iterative design process, the drafting of the survey questionnaire.

Chapter 5: Survey Questionnaire Development

This chapter presents the first step of the iterative survey questionnaire design process discussed in Chapter 4. Draft survey questionnaires were prepared to answer the research questions posed in Chapter 3 by estimating the willingness-to-pay for construction and road noise abatement. The questionnaires were designed based on the guidelines proposed by Johnston et al. (2017). Further, the survey questionnaire was designed to be in line with ethical requirements and to safeguard the well-being of respondents.

The chapter begins with an overview of the draft survey questionnaires in Section 5.1. The veracity of the estimates from a stated preference survey depends on the consequentiality and incentive compatibility of the survey, both of which are discussed in Section 5.2. Sections 5.3 to 5.8 discuss the design of the valuation question in the choice modelling survey. The baseline scenario is presented in Section 5.3, followed by a discussion of the framing of the survey in Section 5.4. Given that a market for noise abatement does not currently exist, no payment vehicle for noise abatement exists in reality. Hence, Section 5.5 discusses various candidate payment vehicles. Section 5.6 outlines candidate attributes in the construction and road noise surveys. Among these attributes are the changes to noise levels, which provide insights to answer Research Questions (1) and (2). Sections 5.7 and 5.8 discuss the layout of audio- and text-based choice sets respectively. Preparation of the text-based survey questionnaire addresses Research Question (3). Section 5.9 provides details on the demography questions and the hearing acuity test, which provides information to answer Research Questions (4) to (6). Since the choice modelling survey presented potentially annoying noise to respondents, careful design of the survey questionnaire is required to safeguard respondents' well-being. Section 5.10 discusses the ethical considerations in the design of the survey questionnaire.

5.1 Overview of draft survey questionnaires

In this section, an overview of the survey questionnaires is presented. The design considerations in each part of the questionnaire are presented in later sections.

Two survey questionnaires were developed to estimate the value associated with publicly mandated construction and road noise abatement. The questions in these two questionnaires are broadly similar, with the exception that one questionnaire is focused on construction noise abatement while the other is focused on road noise abatement.

The survey questionnaires comprised of four parts. First, an introduction to the survey was presented to the respondents and informed consent was sought. Screening questions on respondent age and residency status were also asked. Respondents were only eligible to participate in the survey if they are Singapore residents (i.e., citizen or permanent residents) and are at least 18 years old. Prior medical conditions related to respondents' hearing were also asked. Specifically, respondents were asked if they have been diagnosed with severe migraines or tinnitus as well as whether they have any existing hearing disorders. Respondents were also asked about whether they have lived near construction sites or roads and, if so, the annoyance caused by the noise. A recording of construction or road noise was presented to respondents and respondents were asked to compare this noise with the noise experienced at their homes. The mitigation measures undertaken by respondents to reduce the impact of noise were also asked.

The second part of the survey questionnaire was the choice modelling question. The choice modelling questions enable the estimation of the marginal benefits of noise abatement. This part of the survey begun with a description of the policies to reduce noise in Singapore as well as the possible changes to these policies. Respondents were informed that these changes to noise control policies are costly and a payment vehicle was described for respondents to pay for these changes. A detailed explanation of the choice sets layout was also provided to the respondents.

The respondents were then asked to complete eight choice sets. Each choice set asked respondents to choose their preferred alternative from three choices, namely, the status quo and two alternatives with proposed changes to the levels of a fixed set of attributes. While the attributes and levels were different for the construction and road noise surveys, a key attribute in both surveys was the loudness of noise. Unlike previous choice modelling studies, which described the loudness of noise textually, the surveys in this study presented respondents with a recording of construction or road noise. In addition, a second survey questionnaire was presented to a subset of respondents to the construction noise survey. In this survey noise levels were described textually. The attributes and levels used in this survey were similar to those used in the audio-based survey. For both the audio- and text-based surveys, following the choice modelling questions, a series of ancillary questions were asked to evaluate the validity of responses. Further, in the text-based survey, test questions were presented to respondents to ascertain respondents' understanding of the textual description.

Third, the hearing sensitivity of the respondent was measured with a hearing acuity test. There were two parts to this test, namely a descending test and an ascending test. In the descending test, respondents were presented with a 1kHz sound clip at 55dB. Every three seconds, the loudness of the sound clip was reduced by 5dB. The respondent was asked to indicate the loudness that cannot be heard by pressing on a button on the survey questionnaire. In the ascending test, respondents were presented with a 1kHz sound clip at 20dB, which increased in volume by 5dB every three seconds. The respondent was asked to indicate the loudness that could just be heard by pressing on a button on the survey questionnaire.

Fourth, a series of demographic questions was asked. These questions included respondents' gender, dwelling type, household size, ethnicity, income and education attainment.

5.2 Structure of valuation questions

A key part of the survey involved estimating the marginal benefits associated with a quieter environment. This section is the first of six sections discussing the design of the valuation questions. In this section, two broad design considerations are discussed. First, the choice of whether to use a contingent valuation or a choice modelling approach to value the marginal benefits of noise abatement. Second, the consequential frame of the survey is presented.

5.2.1 Contingent valuation or choice modelling?

As discussed in Section 2.3, non-market valuation techniques can be broadly categorised into revealed preference and stated preference approaches. Revealed preference studies require administrative information about the demography of individuals to estimate the marginal benefits from a policy change. The demographic information is not available publicly in Singapore. As such, this study focuses on the stated preference approach to estimate the non-marketed value of noise abatement.

Stated preference studies can further be classified into contingent valuation and choice modelling studies. In a contingent valuation survey, respondents are asked if they are willing to pay a certain amount for multiple policy changes. In contrast to contingent valuation surveys, choice modelling surveys are designed to estimate the willingness-to-pay for several different attributes of a policy simultaneously. Boxall et al. (1996) suggest that a contingent valuation survey can be seen as a choice modelling survey valuing multiple attributes in a single valuation question.

As choice modelling surveys can estimate the marginal benefits of different attributes simultaneously, a choice modelling survey is more appropriate for the purposes of this survey. The ability to estimate the marginal benefits associated with changes in attributes is also useful as the exact structure of policies to reduce construction and road noise has not been finalised by the government. Examples of policy parameters that can be varied include the amount of noise abatement from construction activity and roads, the mitigation methods to reduce noise, and restrictions to days when construction activity can be carried out.

The estimated marginal benefits of these attributes can inform the overall marginal benefits associated with different policy packages (Wardman & Bristow 2004). Hence, the marginal benefits associated with a range of policy options can be estimated with a single choice modelling survey. By comparison, using a contingent valuation approach to estimate the marginal benefits of these policies will require the survey sample to be segmented into sub-samples. Each sub-sample will be presented with a different policy option.[35] As such, administration of the contingent valuation survey may be more complex as compared to a choice modelling survey.

The choice modelling approach can potentially reduce strategic bias as compared to the contingent valuation approach (Wardman & Whelan 2001). In a choice model, respondents are asked to choose their preferred alternative from several different policy options. Hence, the strategic response to each choice set may not be obvious. Conversely, contingent valuation surveys typically ask respondents about whether they are willing to pay a given amount for a proposed policy change. As the strategic response is more obvious in a contingent valuation survey as compared to a choice modelling survey, more respondents may answer contingent valuation surveys strategically.

[35] Respondents to a contingent valuation survey can be presented several policy options. However, research has found that presenting several policy options to respondents can bias the estimated willingness-to-pay due to anchoring effects (Green et al. 1998).

While a choice modelling survey has several desirable properties, the are several benefits associated with contingent valuation surveys. Carson & Groves (2007, 2011) showed that contingent valuation can be incentive compatible if respondents believed that their responses to the survey can influence policy decisions. Specifically, a majority provision rule in contingent valuation survey can incentivise respondents to reveal their true preferences. Such a majority voting rule can only be implemented when respondents make a single choice and respondents are informed that the option which gets the majority of votes will be implemented (Scheufele & Bennett 2013). However, in choice modelling surveys conducted in this thesis, respondents make multiple choices by answering different choice sets. Consequently, none of the decisions made by respondents can be used to establish a majority voting rule. However, a second-best provision rule can be implemented, informing respondents that the policy that achieves the majority of votes is implemented.

Contingent valuation surveys can also be less tedious for the respondent as compared to choice modelling surveys. Contingent valuation surveys typically only comprise of a single valuation question. By comparison, respondents are typically asked to complete several choice sets in a choice modelling survey. In order to reduce survey fatigue, the survey can be pre-tested to ensure that the design was satisfactory and that respondents will not be fatigued by the end of the survey.

Another advantage of contingent valuation surveys is the ease of design and analysis as compared to choice modelling surveys (Wardman & Bristow 2004). Notwithstanding the benefits associated with a contingent valuation survey, the flexibility to estimate the marginal benefits of each attribute afforded by a choice modelling survey makes the latter preferable in the context of this study.

5.2.2 Consequentiality of survey questionnaire

The survey questionnaires are framed to be consequential, i.e., respondents are informed that the outcomes of the survey will affect policies implemented by the government. A consequential survey encourages respondents to reveal their true preferences for noise control (Carson, Groves & List 2014). The consequential framing of the survey questionnaire contrasts with inconsequential surveys, which reassure respondents that the scenarios presented in the survey are hypothetical and will not affect government policies. Inconsequential surveys do not incentivise respondents to reveal their preferences truthfully.

Carson, Groves & List (2014) showed that if respondents believed that the outcomes of the survey can affect policy outcomes and a majority provision rule was provided[36], then respondents will truthfully reveal their preferences when answering the survey. This result was derived by observing that any given respondent may be pivotal to reach a threshold number of votes to achieve the majority provision rule. Further, if achieving the threshold number of votes leads to a higher probability that the government will implement a given policy, then the respondent will be incentivised to reveal their true preferences. This result holds for any probability which is strictly more than zero and does not require that the probability be equal to one. In other words, truthful preference revelation does not require the vote to the binding, so long as the respondent believes that the government is more likely to implement policies which are preferred. However, if respondents do not believe that their response will affect future policies, then there is no incentive to reveal their true responses.

Hence, Carson, Groves & List (2014) argued that inconsequential surveys, such as surveys that sought to reassure respondents that the scenarios in the surveys were hypothetical and will not affect policy decisions, would not lead to truthful preference revelation. They drew their conclusion from the fact that inconsequential surveys sought to convince respondents that their responses have no effect on policy decisions. In contrast to inconsequential surveys, consequential surveys inform respondents that their responses will affect policy decisions by the government. As such, responses to the survey influence policy decisions and respondents were more likely to reveal their true preferences.

As such, the survey questionnaires were framed as being consequential in determining policies to control noise in Singapore. Several elements of the surveys' introduction were designed to establish consequentiality. First, the introduction to the survey sought to establish consequentiality by informing respondents that the surveys were conducted on behalf of the Singapore government. Further, respondents were informed that the outcome of the survey will affect future policies on noise control. Finally, the inclusion of contact persons from the Singapore government reminded respondents that the survey was conducted by the government and provided respondents with a contact point to ascertain the veracity of the survey. These elements of the survey sought to convince the respondent that their responses to the survey will be taken into account when the government revises noise control policies. Since the survey was funded by the Singapore government and the findings will be presented to the relevant agencies

[36] An example of a majority provision rule is 50% of the respondents preferring a specific policy.

in the government, the surveys will inform future cost-benefit analysis of noise abatement policies.

The policy context, mitigation measures and payment vehicles of the survey questionnaire were also designed to be consequential. These elements of the survey were designed to reflect actual policies which may be implemented by the government. The following sections detail the design of these parts of the survey.

5.3 Baseline scenario and noise control policies

In order to frame the choice modelling questions, the current noise situation in Singapore was presented to respondents. Further, respondents were informed about the possible policy options which could be implemented by the government to reduce noise from construction activity and roads.

The scenarios reminded respondents about the geographical constraints faced by a rapidly developing and highly urbanised city. The scenarios presented to respondents for the construction and road noise surveys were:

> Construction noise survey
> Singapore is geographically small, highly urbanised and densely populated. The rapid pace of development has led to a high number of construction sites in Singapore. However, residents living near construction sites may be affected by higher levels of noise.
>
> Road noise survey
> In order to ensure that everyone in Singapore can conveniently travel to other parts of Singapore, the Government has built a network of roads and expressways. However, residents living near these roads may experience higher levels of noise.

The information presented to respondents was designed to be clearly understandable without providing information that was not known to the average respondents. The design of the scenario avoided the use of jargon and did not provide excessive information to the respondent. Provision of excessive information to respondents causes the respondent to become super-informed and responses may not represent the views of the average respondent (Rolfe 1996). Consequently, the provision of excessive information biases the estimated preferences of respondents. As such, Rolfe, Bennett & Louviere (2000) suggest that a balance in information provision such that the causes of noise pollution are clearly explained in simple terms to the respondent. An example of information that may not be known to the average respondent is the wide-ranging adverse effects of noise pollution. Specifically, noise pollution could affect human hearing as well as cause annoyance and could lead to increased occurrence of hypertension and cardiovascular diseases (Basner et al. 2014). As such, the effect of noise on human health is not discussed in the scenario. Consequently, the respondent is not over-informed about the effect of noise and will make decisions based on information known by the average respondent. Since respondents were not over-informed, estimated preferences were more likely to represent the views of an average Singaporean and these estimates will not be biased by super-informed respondents.

The baseline scenario presented to respondents should also accurately reflect the real-world situation to ensure that the valuations obtained from the choice modelling question accurately reflect the preferences of the respondent (Rolfe, Bennett & Louviere 2000). As such, this survey described the baseline level of noise with recorded noise. The noise was played back to the respondent at 75dB to illustrate the noise which respondents currently experience.[37]

The mitigation measures to reduce noise were also presented to the respondent. These mitigation measures informed respondents about the policies which could achieve noise reduction. The mitigation measures for construction noise and road noise were:

<u>Construction noise survey</u>

1) Regulate construction equipment and practices in order to encourage construction companies to emit lower levels of noise.
2) Reduce the noise emitted from construction sites with noise barriers.
3) Retrofit windows with sound-proof double-glazed windows.
4) Disallow or restrict construction activities at nights and on weekends as well as public holidays.

<u>Road noise survey</u>

1) Tighten regulations for noise emissions from vehicles.
2) Reduce the noise emitted from major roads and expressways with noise barriers.
3) Construct roads with low-noise pavement material.
4) Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.

In order to convince respondents that these policies can be practically implemented, the government was consulted on noise abatement policies that it can potentially implement. Specifically, discussions with operations officers from the Pollution Control Department at the

[37] Ideally, the baseline level of noise should be varied depending on the noise levels experienced by the respondent at their homes and a pivot design used to generate changes to this baseline level of noise. However, technical limitations preclude the use of individual-specific noise levels. In particular, it will be necessary to record noise on-the-fly and transformed on the survey tablets to new noise levels. Given the technical complexity, the questionnaire was designed based on the mean baseline noise level that can be pre-programmed into the survey questionnaire.

National Environment Agency and policy officers from the Environmental Policy Division at the Ministry of the Environment and Water Resources provided insight into mitigation measures to control construction noise. Similarly, the Road & Commuter Infrastructure Development Group at the Land Transport Authority provided suggestions for road noise mitigation measures. Presenting respondents with realistic and feasible mitigation measures sought to convince respondents that the proposed mitigation measures can be implemented, reinforcing the consequentiality of the survey questionnaire.

5.4 Choice of willingness-to-pay or willingness-to-accept

In order to understand an individual's preferences for improvements to environmental quality, the survey questionnaire can use either a willingness-to-pay or a willingness-to-accept frame. In a willingness-to-pay frame, the survey asks respondents whether they will be willing to increase their expenditure to pay for a quieter environment. Alternatively, in a willingness-to-accept frame, the survey asks respondents how much they will accept as compensation should a proposal to reduce ambient noise not occur.

Earlier studies have recommended the use of willingness-to-pay framing for stated preference surveys. For example, the NOAA panel recommended the use of the willingness-to-pay frame as a willingness-to-pay survey generally yields more conservative estimates as compared to willingness-to-accept surveys (Arrow et al. 1993). Hence, the panel suggests that the willingness-to-accept frame could lead to an overestimate of the value of an improvement to the environment. A review by Horowitz & McConnell (2002) found that willingness-to-accept estimates were indeed substantially higher than willingness-to-pay estimates. Further, the ratios of willingness-to-accept to willingness-to-pay estimates are found to be highest for non-market goods. List & Gallet (2001) also found that willingness-to-pay was incentive compatible as respondents to a willingness-to-pay survey had a lower strategic bias as compared to a willingness-to-accept survey. Respondents to a willingness-to-pay survey were more likely to correctly state their true preferences as the choice task in a willingness-to-pay survey was more familiar as compared to a willingness-to-accept survey. Nape et al. (2003) suggested that another source of upward bias from willingness-to-accept surveys is hypothetical bias. The researchers suggested that results from willingness-to-accept surveys should be viewed *a priori* as an overstatement of the true valuation. Further, the upward bias depends on individual characteristics and cannot be scaled linearly across the survey sample.

Advances in the stated preference methodology since the publication of the NOAA report suggest that the divergence in willingness-to-pay and willingness-to-accept estimates is due to the perspective of the respondent (Johnston et al. 2017). In particular, the appropriate frame is dependent on the institutional context presented to survey respondents. A key institutional factor determining the choice of survey frame is the allocation of property rights at the status quo (Perman et al. 2003). Specific to this survey, if households have the rights to a quiet environment, then they should be compensated should a proposed reduction in noise not occur. In this case, the appropriate measure should be the willingness-to-accept frame from the resident's perspective. Conversely, if respondents do not have the rights to a quiet environment, then they will have to pay for a proposed reduction in noise levels and a willingness-to-pay frame should be used.

There are two property rights regimes for construction noise in Singapore, demarcated by the regulations on construction noise. The first regime occurs when the noise level is above 75dB. In this case, households have the right to a quieter environment as construction companies are not permitted to emit noise exceeding 75dB as measured at the nearest residence. Companies that violate these regulations can be penalised with fines (Singapore Statutes 2011). Consequently, the willingness-to-accept frame is more appropriate when noise levels exceed the regulatory level of 75dB.

However, when the noise level is below the regulatory limit, households do not have defined rights to a quieter environment. If households prefer to reduce noise below 75dB, they will have to pay for the noise abatement measures. The notion that there are no defined property rights below 75dB is reinforced by government schemes to reduce noise. Most notably, the government administered Quieter Construction Fund (QCF) and the Quieter Construction Innovation Fund (QCIF) provide incentives to companies to reduce noise below 75dB by subsidising purchase and implementation of quieter construction equipment (NEA 2016, 2019). As such, if the noise level is below 75dB, the appropriate frame is the willingness-to-pay frame.

In contrast to construction noise regulations, road noise is controlled by regulations on vehicular noise emissions. These regulations include restrictions to modifications of the emission systems for in-use vehicles, and noise emission standards on new vehicles. Hence, there are no defined property rights for road noise and if residents living near roads prefer a quieter environment in their homes, they will have to pay for noise abatement measures at their homes.

The focus of both surveys is a reduction in noise levels from the status quo. Hence, the willingness-to-pay frame was used for both surveys.

5.5 Candidate payment vehicles

This section presents several candidate payment vehicles for respondents to pay for noise abatement measures that reduce ambient noise. Johnston et al. (2017) suggest that the payment vehicle should be realistic, credible, familiar and binding for all respondents. However, the choice of the payment vehicle is dependent on the survey context and there is no consensus in the literature on the selection of specific payment vehicles.

There is currently no payment vehicle for residents in Singapore to pay for lower levels of noise. Hence, the choice of payment vehicle for both surveys is problematic. Since there is no clear choice for the payment vehicle, several payment vehicles are presented in this Section. The pros and cons of each of these payment vehicles are discussed. These payment vehicles will then be pre-tested during the focus group discussions.

Taxes. In reality, government expenditure to reduce noise is funded by tax revenue. Hence, implementing more noise abatement measures requires higher levels of expenditure paid for by increased taxation. As such, a possible payment vehicle may be increased taxes paid by every Singapore resident.

The two main sources of taxes paid by residents are the personal income tax as well as the goods and services tax, both of which account for around 14% of government revenue in 2017 (MOF 2018b). As such, these taxes could potentially be used as payment vehicles. Respondents are familiar with these vehicles as they are levied on a large proportion of the population.

However, there are several downsides to the use of these taxes as the payment vehicle. First, respondents may be averse to paying additional taxes as taxes accrued to the government are generally not earmarked for specific purposes. As such, additional tax payment may be viewed as fungible and government spending is not transparent to the general public. Consequently, respondents may feel that increased tax payments will not directly lead to the effective provision of a quieter environment since a detailed breakdown of government expenditure for specific government policies is not available publicly. Respondents may respond by protesting against the payment vehicle, leading to an underestimate of the marginal benefits of noise abatement.

Second, in general, Singapore's personal income and goods and services taxes are collected based solely on the individual's income and expenditure respectively. Payment for noise abatement may cause individuals affected by noise pollution to pay more taxes to reduce the level of noise. This unequal imposition of tax may be rejected by the average respondent. Further, residents living near noisier areas are likely lower-income individuals who will likely reject a higher tax payment to fund noise abatement measures.

Third, specific to income taxes, only around 45% of Singapore's residents pay income taxes. Singapore's population is 3.93 million[38] in 2016 and only 1.76 million individuals paid taxes in the same year (IRAS 2018; Statistics Singapore 2018d). Since a substantial proportion of the population does not pay income taxes, it may be difficult for these respondents to envision having to pay taxes solely for noise reduction purposes. The lower income residents will also be likely to be living in noisier areas, and a proposed increase in taxation for these residents may cause higher rates of protest responses.

Fourth, Singapore's government proposed an increase in goods and services tax in the 2018 government budget (MOF 2018a). There was a significant public backlash against the proposal (Chia 2018; Heng 2018; Lam 2018). As such, use of the goods and services tax as the payment vehicle may result in an increased proportion of protest responses.

Maintenance fees. Another candidate payment vehicle is property maintenance fees, which go towards the upkeep of common property within housing estates. Examples of fees include Service and Conservancy Charges (S&CC) paid by residents in Singapore's public housing and condominium maintenance fees paid by private housing residents.

Respondents may perceive maintenance fees to be a more targeted payment vehicle as compared to taxes. Unlike taxes, funds collected from maintenance fees are used primarily for the upkeep of the estate, such as the cleaning and landscaping of common areas, as well as the maintenance of lifts, plumbing systems, and waste disposal chutes. Hence, these fees are earmarked for specific purposes and use of the funds is more transparent as compared to taxes.

[38] In total there were 3.93 million Singapore citizens and permanent residents in 2016.

Consequently, respondents may prefer the use of maintenance fees as compared to taxes as the payment vehicle.

However, there are several shortcomings to the use of maintenance charges. First, unlike taxes, maintenance charges are paid to the municipal or estate manager, while, the control of noise is regulated at the national level. Hence, respondents may not believe that the municipal authority or estate manager collecting the maintenance charge is able to affect changes to noise policy.

Second, the current level of maintenance charges may anchor the valuation of the respondent. Among the 80% of Singaporeans living in public housing, the current level of maintenance charge range from S$19.50 to S$95 per month (Baker 2018). As such, the use of maintenance charges as the payment vehicle may inadvertently cause respondents to compare the change in payment with their current payments. Since the current level of payment is not related to a respondent's valuation of noise abatement measures, the anchor may result in inaccurate estimates of the marginal benefits of these measures.

Community funds. A third alternative for the payment vehicle is a compulsory contribution to a community fund. Contributions to community funds are used to fund improvements to public housing in Singapore. These upgrading programmes include the lift upgrading and the housing improvement programmes (HDB 2018b). In these programmes, residents are polled on whether they will like to upgrade the lifts and common facilities within their blocks. If more than 75% of a block's residents vote in favour of the programme, the project is implemented and each household pays a portion of the cost of the project to the community fund. The remainder of the cost is subsidised by the government.

Adopting this payment vehicle for the purposes of the survey entails informing respondents that they will be contributing to a community fund which will then be used to implement noise abatement. Among the candidate payment vehicles, contribution to community funds appears to the most targeted, since the collected funds will only be used for the implementation of noise abatement measures.

Singapore residents are also familiar with the concept of contribution a community fund to improve the neighbourhood. The majority of the population live in public housing[39] and upgrading programmes have been completed in more than 100,000 homes, with 139,400 more

[39] Public housing in Singapore refers to apartments built by the Housing Development Board (HDB). These apartments are subsidised by government.

homes currently undergoing upgrading (Au-Yong 2017). Hence, a substantial proportion of the population has first-hand experience with contributing to a community fund. Among residents living in private housing, three-quarters of residents live in condominiums (Statistics Singapore 2018a). Condominium residents contribute to a Management Corporation Strata Title fund which is used for upgrading activities within the condominium. Among the remaining population, most will have second-hand information from their extended family or friends.

Nonetheless, similar to maintenance charges, the structure of current policies may anchor the respondent's perspectives of contribution to community funds as the payment vehicle for this survey. Upgrading programmes are subsidised by the government to reduce the burden on households. For example, subsidies for the home improvement programme range from 87.5% to 95% (HDB 2018a). This high level of existing subsidy may cause respondents to assume that the government will be subsidising the implementation of noise control measures, biasing the estimates of marginal benefits associated with these measures. For instance, if respondents assume that the government will be covering some of the costs of noise abatement, they may under-report their valuation of noise abatement.

In order to reduce the effects of anchoring, the payment vehicle can be a contribution to a community fund, without mentioning the parallels to the upgrading programmes. The survey questionnaire sought to dissociate the contributions from the subsidies provided by the government by not mentioning the upgrading programmes.

All three of these payment vehicles were pre-tested during the focus group discussions. Participants of the focus group discussions were also asked to discuss other possible payment vehicles. On balance, the contribution to community funds garnered most support among participants of the focus group discussions.

5.6 Candidate list of attributes

The choice modelling technique involves respondents being presented with a series of choice sets. Each choice set contains different combinations of levels for a set of attributes. Hence, the design of attributes and levels is a key component of the choice modelling questionnaire. This section presents a candidate list of attributes and levels which were considered in the preliminary design of the choice modelling survey. The attributes were chosen based on the characteristics of the construction and road noise as well as the factors which may cause annoyance for residents experiencing noise pollution.

5.6.1 Candidate attributes for the construction noise survey questionnaire

The first attribute for the construction noise survey questionnaire was the loudness of construction noise. As discussed in Section 2.5.1, the characteristics of noise can be described by the noise level as well as the frequency of the noise. In Singapore, the loudness of construction noise is constrained by regulations imposed by the National Environment Agency (NEA) of Singapore. Specifically, the maximum level of day-time[40] noise from construction sites is 75dB averaged over a 12-hour period as measured from the façade of the nearest residential building. In order to control the peak level of noise, an additional limit of 90dB averaged over a 5min interval is imposed.

These regulations imply that the peak loudness of noise from construction sites is 90dB and the loudness of noise from construction sites averaged over the course of the day is 75dB. For the purposes of designing the choice modelling survey questionnaire, the maximum level of recorded noise was set at 75dB. While it might be desirable to estimate the willingness-to-pay for louder noise levels, the lower noise level was chosen in order to ensure that participants are not exposed to noise levels which may damage their hearing.

The minimum loudness for construction noise was set at 55dB. This loudness of noise is the lowest level of noise mandated in other major cities (Gilchrist, Allouche & Cowan 2003; Granneman 2013), suggesting that it is currently not technically feasible to reduce noise from construction activities below this level. Furthermore, the loudness of 55dB is equivalent to NEA's current maximum permissible level of noise from construction activity in the night (i.e., between 10pm and 7am). The levels for the loudness attribute were to be 5dB increments from 55dB to 75dB.

The second noise characteristic that could affect preferences for construction noise is the frequency of construction noise. For instance, psychoacoustic studies have found that noises of different frequency are perceived differently (Fastl & Zwicker 2007) and may cause different levels of annoyance (Lee, Hong & Jeon 2015).

In order to investigate the frequency distribution of construction noise in Singapore, recordings of construction sites at different stages of completion were taken.[41] Singapore's construction noise regulations stipulate that the average day-time noise cannot exceed 75dB as

[40] Day-time is defined to be between 7am and 7pm.
[41] The recordings were taken with a BSWA BR2022 binaural microphones attached to a Zoom H4n Pro recorder. The equipment for the recordings were provided by Dr Lau Siu Kit from the Department of Architecture at the National University of Singapore.

measured from the façade of the nearest residence (Singapore Statutes 2011). Hence, the recordings were also taken at the façade of the nearest residence.

Key considerations taken into account when choosing the sites include: (i) the stage of construction; (ii) the equipment used in the construction; and (iii) whether there are residences near the site. These recordings were taken at the nearest residential building so that the recordings are representative of the noise experienced by residents. In total, recordings were taken at six construction sites in Nov-17 and Dec-17 (Table 5-1).[42]

Table 5-1 List of sites where construction noise recordings were recorded

	Recording Site	**Construction Activity**
1	Existing residences at Ang Mo Kio Ave 2 & 3	Demolition with crusher
2	Existing drainage work along Woodlands Drive 73	Demolition with excavator-crusher
3	Proposed six blocks of 7-storey hospital at Woodlands Drive 17 and Woodlands Ave 12	Construction of foundation
4	Proposed 4-storey nursing home at Venus Drive	Construction of foundation
5	Proposed two blocks of 4-storey commercial development along Woodlands Ave 3	Construction of superstructure
6	Proposed 6-storey single user data centre along Woodlands Ave 6	Construction of superstructure

Note: The recordings were taken at the façade of the nearest residence.

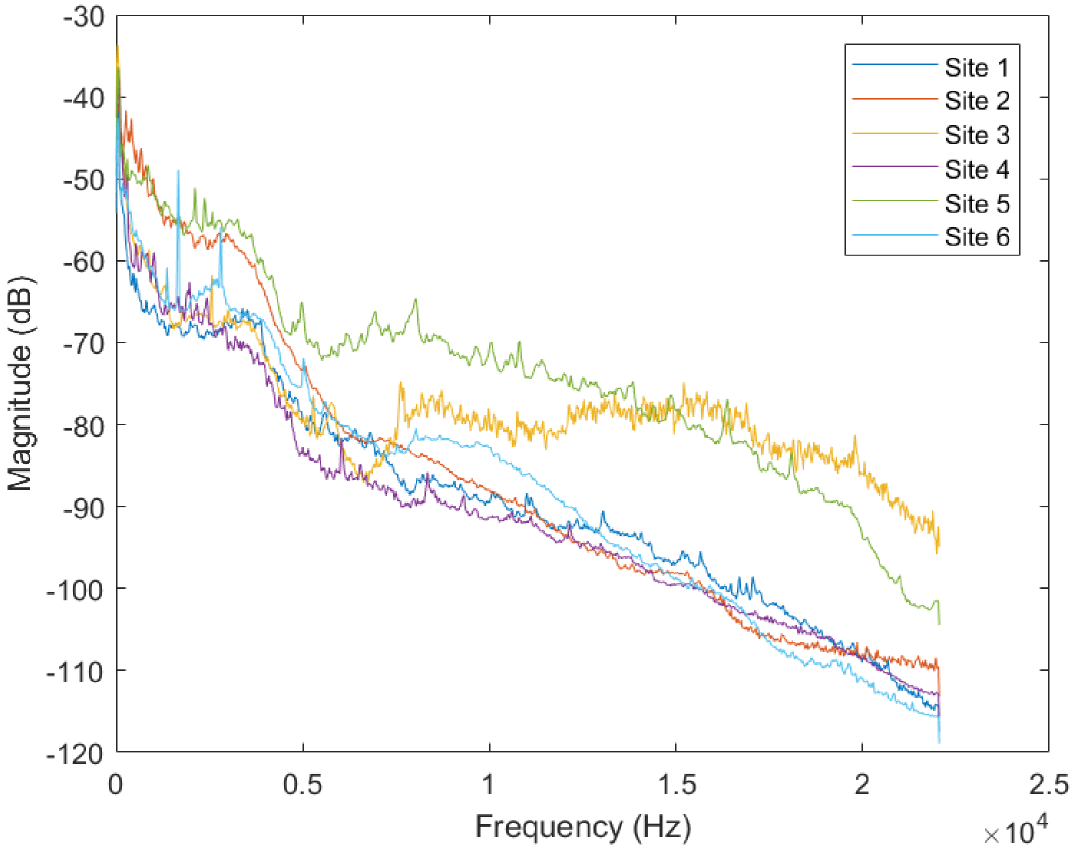
The recordings were analysed with Welch's method in order to estimate their power spectra.[43] The results are shown in Figure 5-1. The power spectral density suggests that low-frequency noise was the largest component of the recorded construction noise. Specifically, relative to the power of the recording, the average power level of frequencies below 500Hz was -45dB.[44] However, the average power of frequencies from 500Hz to 5kHz was -59dB and from 5kHz to 22kHz was -80dB. Recalling from Section 2.5.1 that a 10dB change corresponds to a 10-time change in power, the analysis suggests that the average power of frequencies was around 26-times larger than the average power of frequencies from 500Hz to 5kHz and around 3,000 times larger than the average power of frequencies from 5kHz and 22kHz.

[42] These sites were chosen in consultation with the Pollution Control Department (PCD) at the NEA.

[43] The Welch method first splits the signal into data segments of equal length, with a fixed number of overlapping points (Welch 1967). Next, the overlapping data segments are windowed, with more influence placed at the centre of the segment as compared to the edges. Finally, a discrete Fourier transform is performed on each data segment and these outcomes of these transforms are averaged. For the purposes of this study, a data segment length of 2048 with an overlap of 67% were chosen. The Hamming window was applied to each data segment (see Koopmans (1995) for a description of the Hamming window). The estimates were carried out with Matlab's pwelch function (Matlab 2018).

[44] The decibels are negative as they are relative to total power of the recorded noise. Since each frequency only contribute a fraction of the total power, the ratio of the power of each frequency to the total power is less than one and the logarithm of this ratio is negative.

Figure 5-1 Power spectral density of recorded construction noise



These results are in line with the findings of Piercy, Embleton & Sutherland (1977) and Bass, Sutherland & Zuckerwar (1990), with all finding that the atmospheric absorption of noise is predicted to be higher for higher frequency noise (see Section 2.5.2 for a review of atmospheric absorption).

This analysis suggests that if receptors are situated sufficiently far away, construction noise will likely sound similar and low-frequency noise will be louder than other frequencies. Consequently, in the survey questionnaire, the only variation in loudness was used as an attribute. The different recordings of construction noise were played to focus group discussion participants to ascertain whether there is a discernible difference in the frequency of the noise.

Other candidate attributes which may affect the preferences of respondents were related to the timing of when construction noise is experienced. There were four candidate attributes related to the timing of construction noise. The first attribute was related to the days when construction activity is prohibited. When construction activity is prohibited, no noise is emitted from the construction site and the annoyance associated with construction noise is eliminated. The current regulations prohibit work on construction sites on Sundays and Public Holidays. However, Singapore's labour force has a five-day work week and most residents do not work on Saturdays. Consequently, residents may be annoyed by the exposure to construction noise on Saturdays. Residents may also value a reduction in noise levels on the eve of Public Holidays. Consequently, possible levels considered were extensions of days when construction activity is prohibited to Saturdays, Sundays, and Public Holidays as well as Saturdays, Sundays, eve of Public Holidays and Public Holidays.

The second and third candidate attributes relate to the times of day when construction activity starts and ends respectively. Current regulations mandate that construction activity can only commence at 7am and should end by 7pm.[45] Consequently, working residents who have yet to leave their house by 7am in the morning may be adversely affected by construction noise. Similarly, residents who return from work earlier than 7pm may prefer that construction activity ends earlier so that they have a quieter environment at home.

The fourth candidate attribute relates to the duration of construction activity. For example, residents may prefer a construction site with a shorter construction duration but with higher levels of noise. Conversely, residents may prefer a longer construction duration, but with lower levels of noise. As such, another candidate attribute may be the duration of construction activity.

Finally, cost was also included as a candidate attribute. The levels for the cost attribute was refined during the focus group discussions.

Given the discussion in the preceding sections, the candidate list of attributes and levels affecting road noise are summarised in the table below.

[45] More precisely, noise from construction activity is subject to a much tighter limit of 65dB averaged over a 1hr period and 55dB averaged over a 1hr period from 7pm to 10pm and from 10pm to 7am respectively. Discussions with the Pollution Control Department (PCD) suggest that, in practice, most construction sites cease activity by 7pm.

Table 5-2 Candidate attribute and levels for construction noise survey

Attribute	Levels
Loudness of construction noise (dB)	**75**; 70; 65; 60; 55
Days where construction activity is prohibited	**Sundays and public holidays only**; Saturdays, Sundays and public holidays only; Saturdays, Sundays, public holidays and eve of public holidays
Time when construction is permitted to start	**7am**, 9am; 10am; 11am
Time when construction is mandated to end	**7pm**, 6pm, 4pm, 3pm
Duration of construction activity	12 months less; 6 months less; **No change**; 6 months more; 12 months more
Cost (S$)	**0**; 20; 40; 60; 80; 100

Note: Levels are separated by semi-colons. Baseline alternatives are bolded. The baseline duration of construction activity is 3 years.

5.6.2 Candidate attributes for the road noise survey questionnaire

Similar to construction noise, the first attribute considered in the design of the road noise survey questionnaire was the loudness of road noise. In Singapore, the target loudness of road noise is 67dB as measured from the façade of the nearest residence (Ng 2017). However, Martin & Diong (2017) measured the ambient noise levels in Singapore and found that the majority of residents were exposed to noise louder than the target level of noise. Specifically, Martin & Diong estimate that around 57% of the population experienced noise louder than the target level of noise at their residence. Consequently, the maximum level of noise for the road noise survey is set at 75dB, similar to the construction noise survey. Respondents in the focus group discussions were asked whether they experience similar loudness of noise. The levels of noise were defined as a 5dB reduction from 75dB until a minimum loudness of 55dB.

The second characteristic of road noise is the frequency of road noise. Similar to construction noise, a series of noise recordings[46] were taken at various expressways and arterial roads[47]. The list of sites where noise recordings were taken is shown in Table 5-3. The choice of recording sites was mainly based on the volume of traffic on the road. Since minor roads have low volumes of traffic and cause lower levels of annoyance for residents, the recordings focused on expressways and major arterial roads. Similar to the construction noise recordings, these recordings were taken at the façade of the nearest residence.

[46] Similar to the construction noise recordings, the road noise recordings were taken with a BSWA BR2022 binaural microphones attached to a Zoom H4n Pro recorder provided by Dr Lau Siu Kit.

[47] The choice of expressways and arterial roads were provided by the Road & Commuter Infrastructure Development Group (RCID) at LTA.

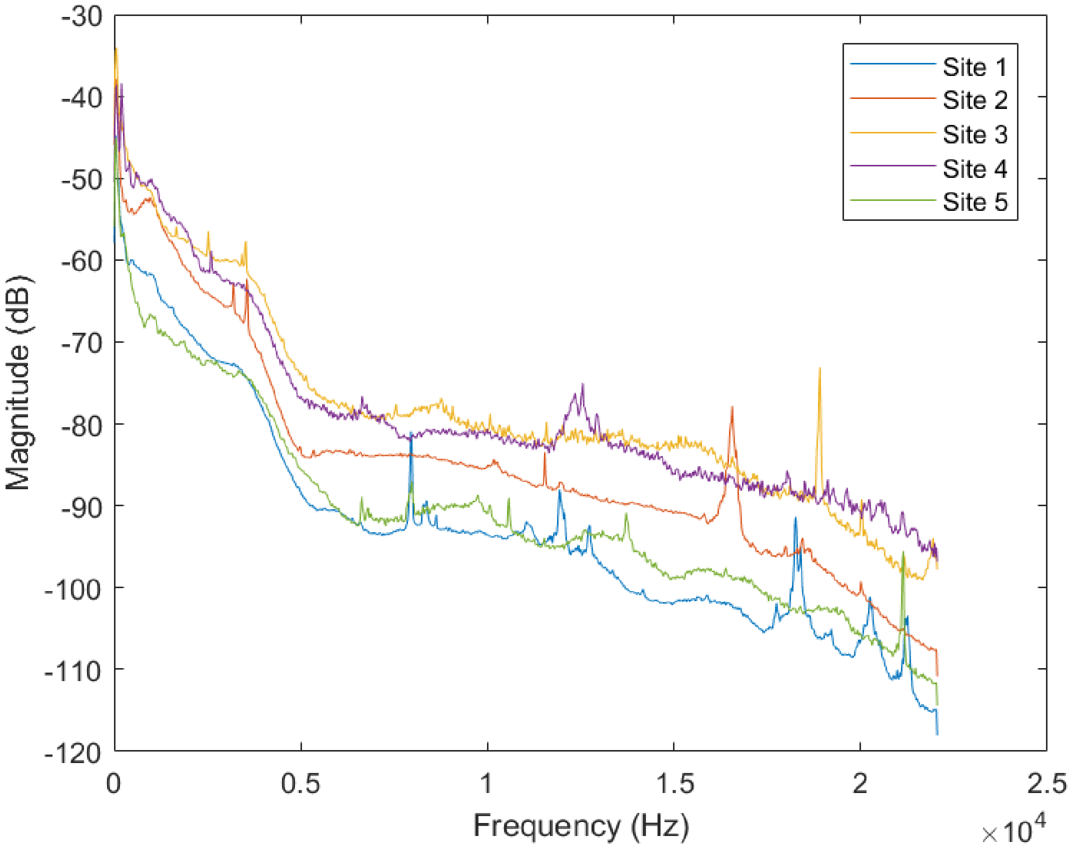
Table 5-3 List of sites where construction noise recordings were taken

	Recording Site	Type of Road
1	Central Expressway (CTE)	Expressway
2	Ayer Rajah Expressway (AYE)	Expressway
3	Woodlands Ave 12	Major arterial road
4	Upper Thomson	Major arterial road
5	Ang Mo Kio Ave 1	Major arterial road

Note: The recordings were taken at the façade of the nearest residence.

Similar to the analysis for construction noise, Welch's method was used to estimate the power spectra of the road noise recordings.[48] The results indicated that road noise predominantly comprised of low-frequency noise. Specifically, relative to the power of the recording, the average power level of frequencies below 500Hz was -45dB, which falls to -59dB for frequencies between 500Hz and 5kHz and -85dB for frequencies between 5kHz and 22kHz. These results were symptomatic of the higher atmospheric absorption of noise for higher frequency noise.

Figure 5-2 Power spectral density of recorded road noise



[48] Similar to the analysis of construction noise, data segment length was 2048 with an overlap of 67% and a Hamming window was applied. The estimates were carried out with Matlab's pwelch function (Matlab 2018).

One other candidate attribute was the noise abatement measure used to control road noise. Candidate levels for this attribute include: installation of noise barriers near roads; installation of sound-proofing within the house of the resident; construction roads with low-noise surface; and the tightening of regulations on vehicular noise emissions. Preferences for these different measures may differ and the inclusion of this attribute in the choice survey enables the estimation of the marginal benefits associated with different noise abatement measures.

Finally, cost is also included was a candidate attribute. The levels for the cost attribute was refined during the focus group discussions.

Given the discussion in the preceding sections, the candidate list of attributes and levels affecting road noise are summarised in the table below.

Table 5-4 Candidate attribute and levels for road noise survey

Attribute	Levels
Loudness of road noise (dB)	**75**; 70; 65; 60; 55
Noise reduction measure	**None**; Installation of noise barriers near roads; Construction of roads with low-noise surfaces; Installation of sound-proofing within the house of the resident; Tightening the enforcement of regulations on vehicular noise emissions
Cost (S$)	**0**; 20; 40; 60; 80; 100

Note: Levels are separated by semi-colons. Baseline alternatives are bolded.

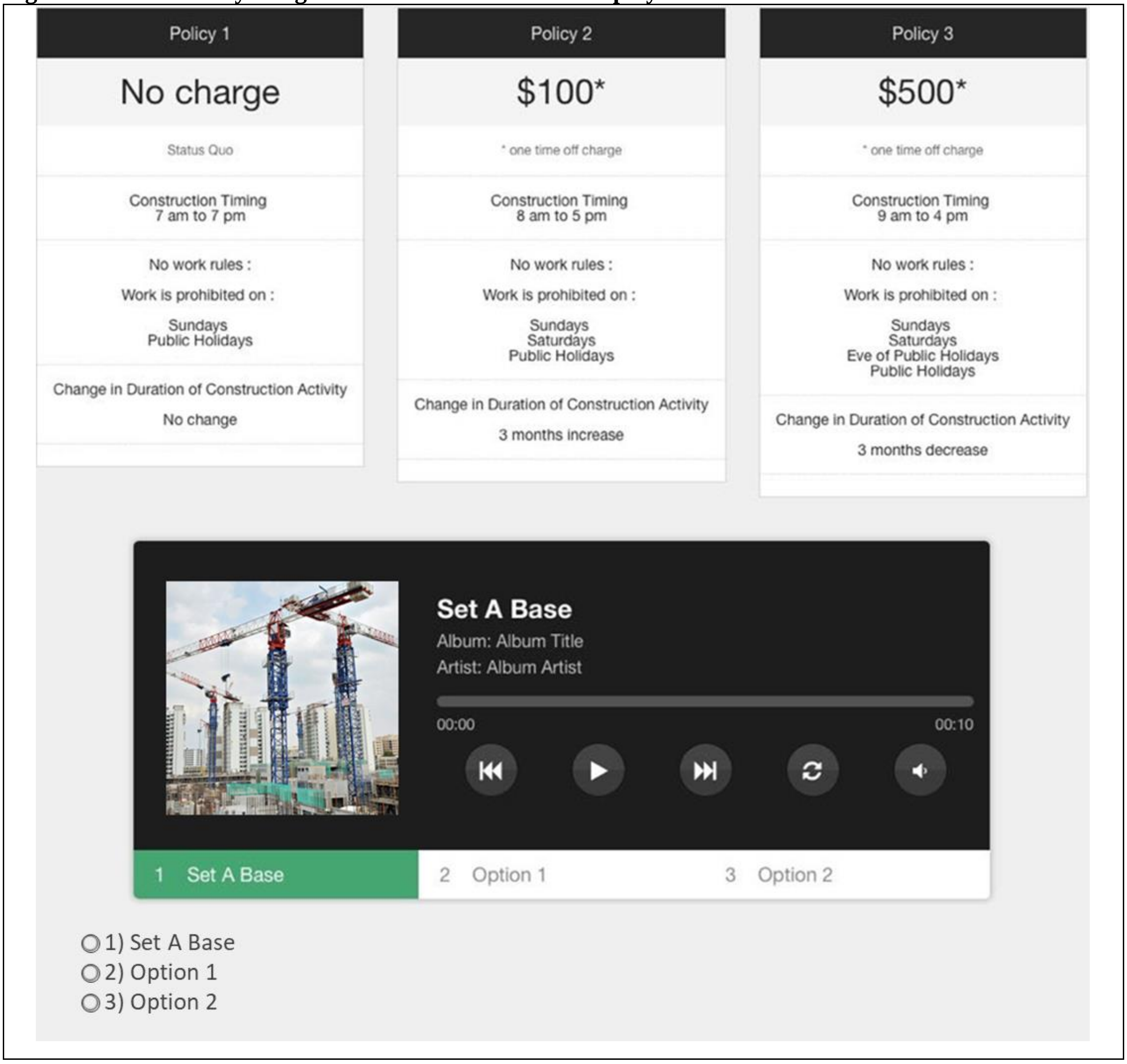
5.7 Audio-based choice set layout

In a choice modelling survey questionnaire, respondents are presented with a series of choice sets illustrating different policy options. The layout of these choice sets should clearly describe the levels of each alternative to the respondents. Previous choice modelling survey questionnaires have used tables with different levels associated with each attribute to illustrate each policy option.

The choice sets used in audio-based survey questionnaires depart from previous choice modelling surveys as recorded noise was played to respondents as part of the survey, necessitating presentation of both audio and textual information to the respondent. Consequently, the survey cannot be conducted on pre-built survey platforms (e.g., Google Forms and Survey Monkey) as these survey platforms do not have the flexibility to include sound clips into the choice sets. As such the survey questionnaires were coded in hypertext mark-up language (HTML) and JavaScript to allow for flexibility in the choice set design.

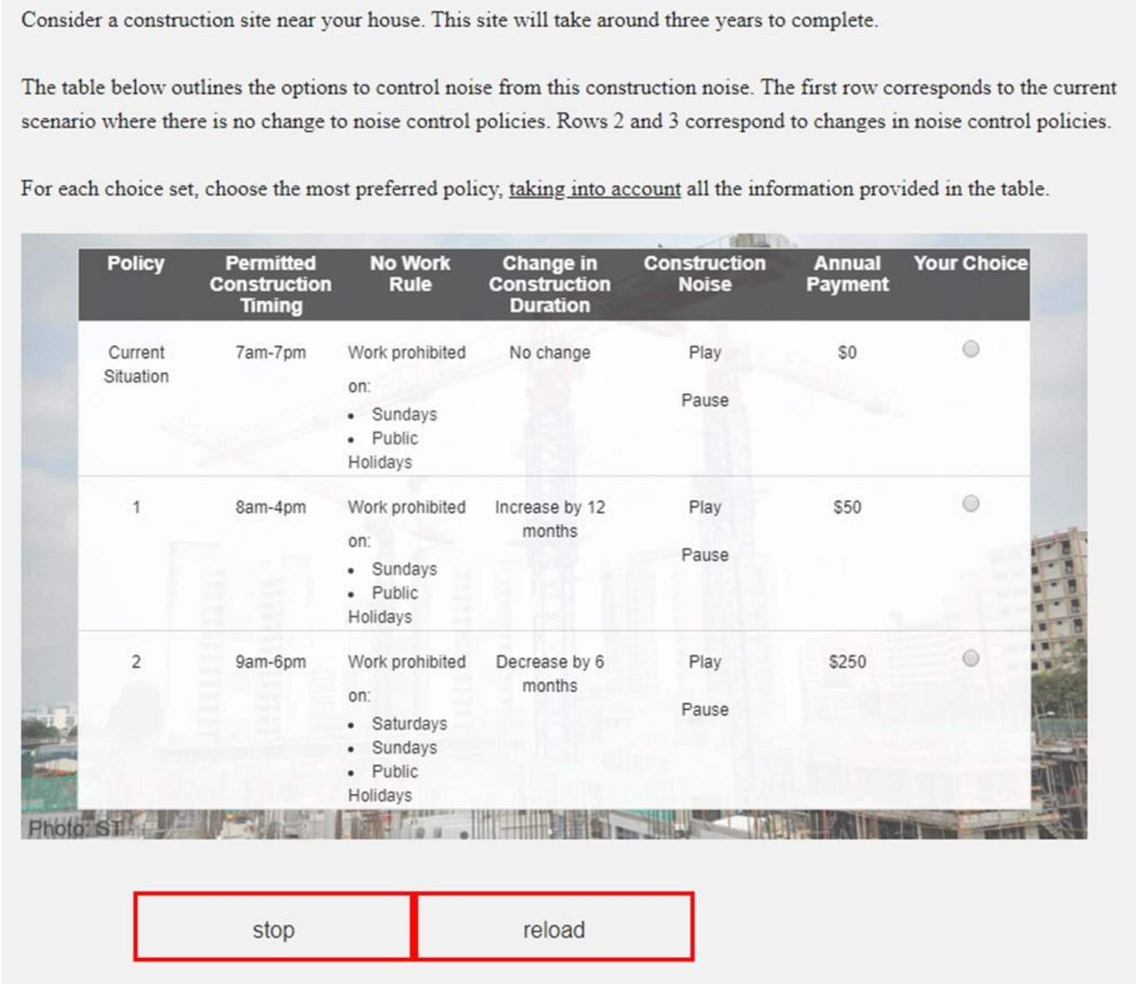
The design of the choice set for textual information was similar to other choice modelling surveys and the text was presented in a table format detailing the different levels for each attribute. However, the audio recordings could be presented to respondents in a variety of different layouts. Two options to present the audio recordings involved a stand-alone audio player (Figure 5-3), and embedding the audio clip into the table containing the textual information for other non-audio attributes[49] (Figure 5-4).

Figure 5-3 Preliminary design of choice set with an audio player



[49] A sample of the choice card with embedded audio recordings, which was eventually used in the finalised survey questionnaire, can be found at: https://chi-hoong.github.io/tryfile.

Figure 5-4 Preliminary design of choice set with embedded audio



Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Your Choice
Current Situation	7am-7pm	Work prohibited on: • Sundays • Public Holidays	No change	Play Pause	$0	○
1	8am-4pm	Work prohibited on: • Sundays • Public Holidays	Increase by 12 months	Play Pause	$50	○
2	9am-6pm	Work prohibited on: • Saturdays • Sundays • Public Holidays	Decrease by 6 months	Play Pause	$250	○

Photo: ST

stop reload

There were pros and cons associated with both layouts. A key advantage of the stand-alone audio player was ease of coding. Preparation of this choice set was straightforward as pre-programmed JavaScript libraries can be used to design the choice set and extensive coding was not required. By comparison, embedding audio into the choice set was more complex and required more extensive coding. Details on the coding of the choice set with embedded audio were provided in Appendix 1.

Notwithstanding the difficulties with programming the choice sets, embedding the audio clips into the choice set made it easier for respondents to make their choice. When the audio clip associated with each option was playing, the row of the table was highlighted, clearly indicating the alternative that is associated with the clip. Hence, respondents were able to see the audio clip associated with each option. This reduced the effort of having to scroll to the audio player to hear the recording. Ease of use is important in the survey as respondents were required to complete eight choice sets over the course of the survey. As such, a more readily understandable layout of the choice set was preferable to a choice set that was more easily programmed. Both choice set layouts were pre-tested during the focus group discussions.

The choice set was designed to fulfil several criteria. First, the audio was calibrated to ensure that the sound pressure level perceived by respondents is equivalent to the design level of noise. For instance, if an alternative in a given choice set is designed to contain a noise with a loudness of 70dB, the sound played by the headphones to the respondent was calibrated to be 70dB. Details of the calibration protocol are provided in Appendix 2.

Second, the choice set was designed to ensure that respondents made their choices based on all information provided. In particular, respondents could make their choices without listening to the sound clip if listening to the sound clips is not mandatory. Consequently, at the start of each choice set, a 10-second sample of the noise recording was played to the respondent. The respondent was unable to skip through the playback, ensuring that they heard the recordings of each alternative before they made their choice.

This design increased the duration of the survey. In total, respondents needed to listen to at least 24 audio clips, namely three clips associated with each alternative for 8 choice sets. The total duration of these clips was 4min. However, this increase in the duration of the survey was necessary to ensure that respondents were fully informed about the noise levels associated with each alternative. There was a trade-off between the length of the survey and obtaining more information from each respondent. As the number of choice sets completed by each respondent increased, more information was obtained from each respondent. However, respondents could be fatigued if they were tasked to complete too many choice sets. The number of choice sets used in the survey questionnaire was pre-tested in the focus group discussions.

Third, the choice set sought to contextualise the noise played to respondents.[50] This was accomplished with both a description of the noise source as well as a picture of the noise source. The policy context presented in Section 5.3 described the source of noise textually. The textual description was reinforced with a pictorial representation of the noise source on the choice set. The picture of the noise source sought to remind respondents that the noise they were listening to was either from construction sites or roads. Studies from the acoustics literature indicate that

[50] Ideally, the context of the survey questionnaire should be specific to the noise level at the household. However, it was not technically feasible to customise the choice sets at the individual level. Hence, the design of choice set sought to illustrate a typical construction site or road in the pictorial representation.

visual stimuli can affect the perceived annoyance associated with noise (Cox 2008; Fastl 2004; Menzel et al. 2008). Hence, providing pictures as background to the choice set sought to remove any ambiguity related to the source of the noise.

5.8 Design of text-based survey questionnaire

In addition to the audio-based survey questionnaire, a text-based questionnaire was also designed. As discussed in Section 2.3.2, previous studies have used a wide range of textual descriptions to communicate different noise levels to respondents. These descriptions can be broadly categorised into changes to physical measures of noise, changes to annoyance levels and changes to contexts. Each of these textual descriptions has limitations. Use of physical measures of noise involves descriptions of the decibel scale, which may not be readily understood by respondents. Changes in annoyance levels require estimation of the correlations between the physical measures of noise abatement and annoyance levels. Finally, changes to context require a context that is readily understood by respondents and assumes that respondents can remember the noise levels they encounter in different contexts.

Changes to noise levels in this survey questionnaire were described with changes in decibels. The main advantage of this methodology was the ability to directly estimate the marginal benefits associated with a 1dB change in noise levels, which can then be directly compared with the audio-based survey. By comparison, estimating the willingness-to-pay for annoyance avoidance requires correlation between annoyance and noise levels as well as assumptions about the applicability of this correlation over the survey sample. Further, no context was readily available that can describe construction noise to respondents. A candidate context change could have been construction noise at different times, however, respondents may confound the value of noise at different times with other attributes at that time. For instance, if respondents were asked whether they would prefer to reduce noise levels in their residence during the weekday to a level they experience at weekend, it is not clear that respondents are valuing solely the change in the loudness of noise or confounding their stated preferences with leisure and other attributes associated with the weekend. Another candidate context may have been changed to house locations, however, residents in Singapore have information about the noise levels at neighbouring houses.

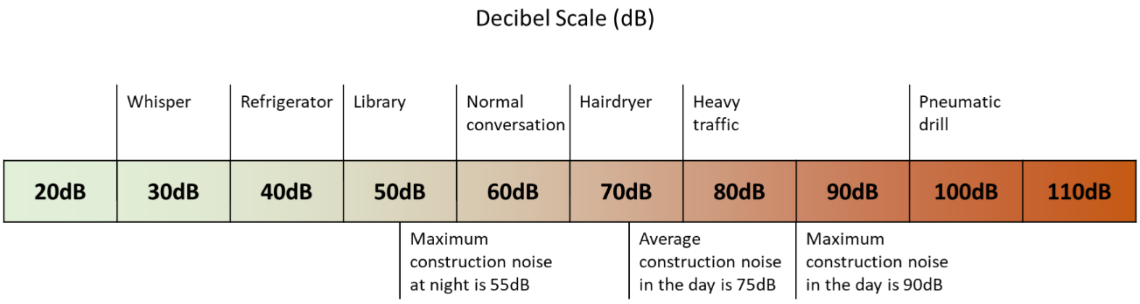
In order to ensure that respondents were informed about the decibel scale, the loudness of different sounds (as measured in decibels) are presented to respondents. These respondents were presented with information on the decibel scale before completing any choice set. The information presented to respondents is shown in Figure 5-5.

Figure 5-5 Explanation of the decibel scale

Consider a construction site near your house. This site will take around three years to complete. When construction is ongoing, noise levels at your house will be higher.

Loudness of noise is described in decibels. A 10dB increase in noise levels approximately corresponds to a doubling of perceived loudness.

Examples of the loudness of some sounds described in decibels are shown below.



As can be seen, noise from construction sites are currently regulated to be below 75dB averaged over a 12hr interval as measured from the nearest house in the day. This is louder than normal conversations at home.

The information on the decibel scale was repeated in each choice set so that respondents were able to refer to the decibel scale when making their choices. An example of the choice set is shown in Figure 5-6.

Figure 5-6 Example of a choice set in the text-based survey

Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

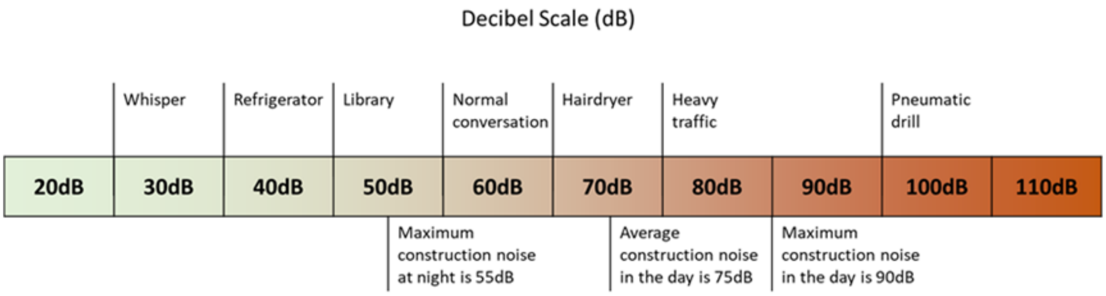
Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment
Current Situation	7am-7pm	Work prohibited on: • Sundays • Public Holidays	No change	75db	$0
1	7am-3pm	Work prohibited on: • Sundays • Public Holidays	Decrease by 12 months	70db	$100
2	9am-6pm	Work prohibited on: • Saturdays • Sundays • Public Holidays	Increase by 6 months	60db	$200

Current Policy

✓ *Policy 1*

Policy 2

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



BACK CLEAR NEXT

If respondents had read and understood all information provided in the scenario and the choice set, they should know that a 10dB increase in construction noise corresponds with a doubling of perceived loudness. Further, the average loudness of construction noise in the day is 75dB and the average loudness of a conversation is around 60dB.

Two methods were used to ascertain respondents' understanding of the information provided in the survey questionnaire. First, the self-reported understanding of the information provided in the questionnaire was elicited. Respondents were asked whether they understood all information provided in the survey questionnaire and whether they were able to imagine the loudness of the construction noise described in the questionnaire. These questions are described in Table 5-5.

Table 5-5 Eliciting self-reported understanding of survey questionnaire

1) Did you understand all the information provided?
   - I understood all provided information
   - I understood most of the provided information
   - I understood some of the provided information
   - I did not understand the provided information

2) When answering the questions, were you able to imagine the loudness of the construction noise in the baseline and proposed changes?
   - I could imagine the loudness of all the noise in the choice set.
   - I had a good idea of most of the noise.
   - I had some idea of the described noise levels.
   - I could not imagine any of the described noise levels.

Second, a series of test questions was asked. Unlike the self-reported understanding questions, the test questions were true/false questions related to information provided in the choice sets (Table 5-6). The first two test questions were related to information provided in the policy scenario and the choice sets, both of which informed respondents that the average loudness of a conversation is 60dB and that the average of Singapore's daytime construction noise was around 75dB. The answer to Question (3) was inferred from the information provided in the policy scenario. Specifically, the policy scenario informed respondents that a 10dB increase corresponded with a doubling of perceived loudness, hence an increase from 50dB to 100dB is far more than a doubling of perceived loudness. Further, Question (4) tested respondents' understanding of the decibel scale.

Table 5-6 Test questions presented to respondents and their corresponding answers

	Correct Answer
1) The average loudness of a conversation is 60dB	True
2) Singapore's average daytime construction noise is around 75dB	True
3) A sound that is 100dB is perceived to be twice as loud as a noise that is 50dB	False
4) The decibel is measured on the logarithmic scale	True

5.9 Hearing acuity and demography questions

Ancillary questions were also included to ask respondents about their prior experiences with construction and road noise, their hearing acuity, and their demographic details. These questions served three purposes. First, responses to these questions enabled comparisons with other data sources to ascertain whether the sample of respondents in the survey was representative of the population in Singapore. For instance, the age and income distribution of respondents can be compared with information from Singapore's census to determine whether all segments of the population were surveyed.

Second, the heterogeneous willingness-to-pay for noise abatement outlined in Research Questions (4) to (6) were estimated based on responses to these ancillary questions. The three main variables of interest were the expenditure on privately-provided noise abatement, the respondents' hearing sensitivity as measured by the hearing acuity test, and the respondent's prior experience with construction or road noise.

Third, the ancillary questions sought to understand whether there were response anomalies and whether respondents viewed the survey questionnaires as being consequential. The remainder of this section discusses the design of these ancillary questions.

5.9.1 Prior experiences with construction noise

An important factor affecting an individual's valuation of the marginal benefits of noise abatement measures may be the individual's prior experience with construction and road noise. If the individual had been exposed to annoying noise from construction activity and roads, her valuation of noise abatement measures might be higher than individuals who are not as annoyed by the noise.

As such, the survey questionnaire asked respondents about their prior experiences with construction or road noise in Singapore. These questions included whether respondents had lived near construction sites or roads, and their level of annoyance due to the noise at these sites. Postal codes of the respondents' residence were also recorded.[51]

These questions served two purposes. First, these questions can provide an estimate of the prevalence of annoyance associated with construction and road noise in Singapore. This information can provide additional impetus for the government to implement noise abatement measures to reduce construction and road noise in Singapore.

Second, these questions enable an estimate of the number of households affected by construction and road noise in Singapore. While it is possible to observe the distance of residences to construction sites and roads, there is no detailed noise map in Singapore which takes into account absorption along the sound path and the variation of noise levels over time-

[51] For the laboratory survey, respondents were asked to provide their postal code, while the surveyor recorded the respondent's postal code in the door-to-door survey.

of-day and day-of-week. Consequently, the estimated prevalence of noise can be used when aggregating the benefits associated with noise reduction.

Besides the questions to understand the respondent's prior experiences with construction and road noise, a series of questions were also asked to understand whether the recordings in the survey accurately represented actual construction and road noise. Respondents were presented with a noise recording, played at 75dB and were asked to compare whether this recording is similar to the noise they have experienced at their residence and state the level of annoyance caused by the noise recordings. These questions provided insight into whether the recordings accurately represented actual noise. For instance, if respondents replied that the recordings were similar to their prior experience with noise, then the noise recordings were likely a good representation of actual noise. Similarly, if respondents were equally annoyed by their prior experience with noise and the noise recordings, then the noise recording elicited a similar level of annoyance and likely provides a good representation of the actual noise.

Finally, respondents were asked about the measures that they had previously taken to reduce noise within their homes. Examples of these abatement measures include installation of double-glazed windows, turning on the air conditioning, purchase of earplugs, and leaving the home when noise is excessive. The costs associated with these measures were also solicited. This question aimed to tease out the costs of noise abatement that respondents have previously implemented. As discussed in Section 2.3.3, implementation of measures to reduce noise within the house could affect the individual's willingness-to-pay for further noise reduction. Nonetheless, the direction of this effect is not clear. On the one hand, an individual may be willing to pay less for noise abatement measures if she has already taken measures to make her house sound-proof. On the other hand, the individual may have implemented sound-proofing measures because she is averse to noise pollution. In this case, the individual's willingness-to-pay may be higher than other individuals. Hence, eliciting prior expenditure on noise abatement enables the estimation of the relationship between privately- and publicly-provided noise abatement.

5.9.2 Design of hearing acuity test

Two types of questions related to an individual's hearing were asked in the questionnaire. First, questions were asked about the respondents' existing medical conditions related to hearing. Specifically, respondents were asked if they had been diagnosed with severe migraines or tinnitus as well as whether they have any existing hearing disorders. Respondents who had existing hearing conditions were not excluded from the survey. However, the surveyors were trained to observe the reaction of individuals with hearing disorders and to stop the survey in the event of adverse reactions to the recorded noise.

Second, a hearing acuity test was also designed to understand a respondent's sensitivity to noise. This test played different loudness of noise to respondents. First, a descending test was conducted. In this test, a 1kHz test tone was played to the respondent at a clearly audible level of 40dB. The test tone descended from this loudness at 5dB intervals until the respondent indicated that she cannot hear the noise. Second, an ascending test is conducted. A 1kHz test tone at 20dB, which was barely audible, was played to the respondent. This test tone ascends at 5dB intervals until the respondent indicated that she could just perceive a noise.

The design of the hearing acuity test was based on the British Society of Audiometry's (BSA) pure-tone air conduction audiometry test (BSA 2011). However, the aims of the acuity test were different from the BSA's air conduction audiometry test. The BSA's air conduction audiometry test sought to ascertain the hearing thresholds of an individual in order to diagnose hearing conditions. However, the acuity test in this survey sought to provide a proxy for a respondent's hearing sensitivity, instead of a complete diagnosis of an individual's hearing condition. Hence, several aspects of the BSA test protocol were not implemented in the hearing acuity test.

First, the BSA test protocol recommends conducting the audiometry test in a quiet environment with ambient noise not exceeding 35dB. However, for the purposes of this survey, this test environment is not practicable, particularly during the field survey.

Second, the BSA test required the use of a specialised audiometer to generate the test tones to be presented to the respondent. For this survey, the test tones were presented to the respondents with the tablet and headphones used for the other parts of the survey questionnaire. Similar to the recordings used in the choice cards, these test tones were calibrated with the protocols outlined in Appendix 2. The use of the tablet was also more cost-effective than the use of the specialised audiometer.

Third, the BSA test was conducted with 8 frequencies, namely, 1kHz, 2kHz, 4kHz, 8kHz, 500Hz and 250Hz, in that order. The test was conducted for each ear individually. However, for the purposes of the survey, only the 1kHz test tone was used and both ears were tested simultaneously. This difference in protocol was mainly to reduce survey fatigue from a lengthy survey. Testing all frequencies required an additional 10min, which increased the duration of the survey from around 30min to 40min. A lengthy survey may lead to a higher incidence of pre-maturely termination of participation. As such, a shortened version of the BSA test was used in the survey.

This test accounted for heterogeneity in willingness-to-pay for noise abatement due to hearing sensitivity that had not been measured in previous studies. For instance, it might be expected that an individual who is insensitive to noise has a lower willingness-to-pay for noise reduction. Further, not controlling for respondents' hearing sensitivity may cause unobserved heterogeneity when analysing the survey data.

5.9.3 Demography questions

In order to understand the characteristics of the respondent, the demographic details of the respondent were also recorded. These questions included the country of residence, type of accommodation, gender, age, education level and income.

The participant's age and residency status were asked at the start of the survey as screening questions. Specifically, only respondents older than 18 years of age and held citizenship or permanent residency status were eligible to participate in the survey. Respondents younger than 18 were excluded for two reasons. First, youth in Singapore are generally in school and depend on their parents for income.[52] Consequently, their willingness-to-pay may not be an accurate representation of the marginal benefits of noise abatement among youths since they will be answering the choice modelling questions based on their parents' incomes. Second, the survey of minors requires further surveyor training in order to satisfy ethical requirements. This training is costly, and the survey company was unable to provide the training.

Respondents who were not Singapore citizens or permanent residents were also excluded from the survey. This exclusion ensured that respondents to the survey have lived in Singapore over the longer term and excluded transient residents such as tourists and temporary workers. The excluded respondents were unlikely to contribute to the provision of noise abatement if the candidate payment vehicle was taxes, maintenance fees, or community funds.

[52] Students complete Singapore's secondary education at ages 16 to 17, and post-secondary education, including, pre-university colleges, polytechnics and vocational schools, will require a further two to three years to complete. School enrolment in Singapore is high, 99.4% of students completed secondary school education in 2016 (Ministry of Education 2017b). Further, around half of the cohort in 2016 progressed to polytechnics and a quarter progressed to vocational schools and pre-university colleges each (Ministry of Education 2017a).

Besides the participant's age and residency status, other demography questions were asked at the end of the survey. Respondents may be more unwilling to answer some of these questions, particularly questions about income and education. Hence, asking these demographic questions at the end of the survey allowed all other information to be captured should the respondent choose to exit the survey as a result of these questions. Respondents have the option to not reveal their demographic information if they preferred to keep this information private.

5.9.4 Questions to ascertain survey validity

Questions were also asked to understand the choices made by respondents. When respondents answer the questions in the choice model, their responses should ideally reflect their true preferences. However, some respondents may have anomalous responses to the questionnaire for a variety of reasons. Of particular concern were protest responses and respondents who did not view the survey questionnaire as being consequential.

Protest respondents refer to respondents who reject the presented choices as they do not agree with the proposed changes to the status quo or the payment vehicle. In a choice modelling survey, respondents reject the proposed changes by selecting the status quo option for all choice sets. Respondents may choose the status quo option for a variety of reasons, including budget constraints, lack of understanding of the survey questionnaire, not believing that the payment will be used effectively, and not believing that proposed changes will be effective. In order to understand the rationale for respondents' choices, respondents who chose only the status quo option were asked to provide reasons for their choice. Respondents who indicated that they had budgetary constraints were not considered protest respondents (Jorgensen et al. 1999). However, respondents who replied that they rejected the choices as they did not think they should be paying for noise abatement and/or they did not think that the contributed funds will be used effectively were treated as protest respondents as they were rejecting the proposed scenario (von Haefen, Massey & Adamowicz 2005).

As discussed in Section 5.2.2, stated preference surveys were incentive compatible only when respondents believed that the survey questionnaire can affect policy decisions and when there is a clearly defined provision rule. In order to understand whether respondents viewed the survey questionnaire as being consequential, respondents were asked whether they believed that their responses to the survey will affect future policies to control noise.

5.10 Ethical considerations in the design of survey questionnaire

A stated preference requires interaction with human subjects and the conduct of the survey should follow established guidelines to protect the well-being of the survey respondents (Johnston et al. 2017). As such, the survey questionnaire was approved by ANU's College of the Asia and the Pacific's Delegated Ethics Review Committee (DERC) and was designed to be in line with Australia's National Statement on Ethical Conduct in Human Research and Singapore's Human Biomedical Research Act.

A key ethical consideration was providing respondents with sufficient information at the start of the survey so that the respondent can provide informed consent for survey participation. In order to provide information to the respondent, a participant information sheet was presented to the respondent before the start of the survey. The information provided in the information sheet fulfilled ANU DERC's requirements of fully disclosing information to survey respondents in order for respondents to provide informed consent.

The participant information sheet began with a brief description of the goals of the research as well as the research design. Next, respondents were informed about the tasks which they will undertake over the course of the survey. Respondents were also informed that their participation is voluntary and that they may decline to take part or withdraw at any time over the course of the survey. The remuneration for participation in the survey was also stated in the information sheet.[53] Respondents were informed that the information collected from the survey will be kept confidential and only aggregated results will be reported. Finally, points of contact, including the researcher as well as an officer from Singapore's government, was provided to the respondent.

After reviewing the participant information sheet, respondents were asked whether they consent to participate in the survey. Respondents only proceeded to complete the survey if they provided consent. Respondents informed the surveyor if they do not provide consent or if they had any concerns related to their participation in the survey. The respondent was able to stop their participation at any time over the course of the survey for any reason.

[53] The renumeration provided to respondents incentivised participation in the survey. Participants in focus group discussions were provided with $100 worth of vouchers, while participants in the laboratory and field surveys were provided with $50 and $10 worth of vouchers respectively. These payments were suggested by the survey company and were in line with other surveys conducted in Singapore.

Another ethical consideration specific to this survey involved the playing of recorded noise to respondents. Exposure to noise that is excessively loud could damage an individual's hearing (Basner et al. 2014; Brown, Rutherford & Crawford 2015; Ising & Kruppa 2004). Hence, the survey questionnaire was designed to ensure that risks to hearing are minimised in both the design and implementation of the research.

The survey questionnaire was designed to safeguard the well-being of the respondent. The design and implement of the survey ensured that risks to respondents' hearing were minimised. The ethical considerations pertaining to the design and implementation of the survey are discussed in turn in the remainder of this section.

5.10.1 Research design

As outlined in Section 5.1, two types of noise were presented to respondents. The first was construction or road noise in Singapore recorded from residences in the vicinity of construction sites or roads. The second was a 1kHz pure tone noise as part of the hearing acuity test.

The noises presented to participants over the course of the survey were within safe limits. The maximum level of noise was 75dB and the total exposure time was less than 10min for each respondent. As discussed in Section 5.6, this level of noise was similar to the noise that respondents were exposed to when living near construction sites or roads. This level of noise was also in line with the current guidelines on noise levels in Singapore.

The proposed level of noise for the focus group discussion was also less than the US National Institute for Occupational Safety and Health (NIOSH's) and Centres for Diseases Control and Prevention (CDC) guidelines for the recommended exposure limit of noise (CDC 2016). Specifically, NIOSH and CDC's guidelines indicated that the average noise level for an 8-hour period should not exceed 85 decibels and the average noise level for a 15-minute period should not exceed 100 decibels.

Recall from the discussions on the physics of noise in Section 2.5.1 that noise levels are measured on a logarithmic scale. Hence, a ten-decibel increase corresponds to a ten times increase in sound pressure intensity (Fastl & Zwicker 2007). Consequently, the sound pressure intensity of our proposed noise level was around 1000 times lower as compared to NIOSH and CDC guidelines for a 15-minute exposure. In terms of perception, 80 decibels will be perceived to be twice as loud as 70 decibels (Fastl & Zwicker 2007). Hence, our proposed noise level was around 8 times quieter than NIOSH and CDC guidelines for 15-minute exposure.

The level of noise presented to respondents was also less than previous studies which have attempted to study human response to noise. For instance, in an early study, Kuwano, Namba & Fastl (1988) played recorded and generated noise ranging up to 90 decibels to participants. In more recent studies, Nilsson (2007) and Hellier et al. (2011) examined the effect of road noise on human annoyance. Nilsson used noises up to 78 decibels, while Hellier et al. exposed participants to noise levels of up to 85 decibels. Lee, Hong & Jeon (2015) examined the effect of construction noise on annoyance and played recorded construction noise with loudness of up to 85 decibels to participants.

5.10.2 Implementation of the survey

Several steps were taken to safeguard the well-being of respondents. First, respondents were informed that they have full control over their participation and they that they could terminate the survey at any point. If, for any reason, respondents wished to exit or stop participation, an exit button within the online survey was provided for respondents to exit the survey immediately. Further, a surveyor was present when respondents were completing the survey. Respondents had the option to inform the surveyor should they choose to exit the survey.

Second, the volume of the sound played to respondents was restricted with a SoundLock programme. This programme ensured that the loudness of the recordings played to respondents did not exceed the designed loudness by preventing respondents from manually adjusting the loudness of the recordings. The programme was password protected so that respondents could not access the programme and change the setting of the tablet.

Third, the sound clips presented to respondents were calibrated based on the model of the headphone and tablets. Different hardware would play the same recording at different loudness, depending on the built-in amplification. As such, the loudness of the original recordings was scaled based on the output of the Audio Technica M40x headphones connected to the Samsung Galaxy Tab 5. This calibration ensured that the loudness of the recordings was equivalent to the designed loudness.

5.11 Conclusion

This chapter presented the key considerations in the design of the survey questionnaire. In response to Research Questions (1) and (2), two audio-based survey questionnaires were prepared to estimate the willingness-to-pay for construction and road noise abatement. These survey questionnaires described noise levels to respondents with noise recordings. In addition to the audio-based surveys, a text-based survey was also designed to estimate the effect of different attribute representation methods on estimated willingness-to-pay. With the exception of the textual description of noise in the text-based survey, the valuation questions in both audio- and text-based surveys were the same. Comparison of the audio- and text-based surveys address Research Question (3).

In order to ensure that respondents provided their true preferences for noise abatement, the surveys were designed to be incentive compatible. This entails the use of a consequential frame, an accurate and realistic policy context, a payment vehicle that was credible, and selection of attributes that were realistic.

Unlike previous surveys estimating the willingness-to-pay for noise abatement, the audio-based survey questionnaires designed in this study presented respondents with both audio and textual information. The need to integrate both audio and textual information into the questionnaire necessitated programming of the questionnaire with HTML and JavaScript as pre-programmed online platforms do not support the presentation of sound to respondents.

To address Research Questions (4) to (6), a series of ancillary questions were also presented to respondents to understand their characteristics. These questions included questions on respondents' prior experience with noise abatement, their hearing sensitivity as measured with a hearing acuity test, and their private expenditure on noise abatement. Questions also asked about respondents' demography and socio-economic status. Further, questions were asked to determine whether a respondent was protesting or thought the survey questionnaire was inconsequential.

As discussed in Chapter 4, preparation of the draft survey questionnaires was the first step of an iterative design process. The next phase of the study involved conducting a series of focus group discussions to refine the survey questionnaires. The following chapter discusses the focus group discussions as well as the refinement to the questionnaire following the discussions.

Chapter 6: Refinement of Draft Survey Questionnaires

This chapter discusses the refinements to the draft survey questionnaire presented in Chapter 5. These refinements were based on a series of focus group discussions conducted in Singapore. The goals of the focus group discussions were three-fold. First, the discussions sought to develop an understanding of the disamenities caused by construction activities and roads. Second, discussion participants were asked to compare the recordings of construction and road noise with noise that they had previously experienced. This comparison provided information on whether the noise recordings were an accurate representation of actual noise. Third, the discussions informed the refinement of the survey questionnaire. These refinements included the attributes in the choice modelling questions, the levels used for each attribute, the policy scenario presented to participants, and the selection of a credible payment mechanism. Participants also completed a draft survey questionnaire and provided direct feedback on the design of this questionnaire.

As discussed in Chapter 4, a total of six focus group discussions were conducted. Four focus group discussions were conducted for construction noise in January 2018, followed by two focus group discussions for road noise in February 2018. The sample size for each focus group discussion was around ten participants who were recruited from Media Research Consultants' (MRC) panel of focus group discussion participants. Each focus group was around two hours in duration.

This chapter begins with a discussion of the focus group discussion protocols in Section 6.1. Next, the broad demographic profile of discussion participants is presented in Section 6.2. The focus group discussions provide an opportunity to understand the disamenities arising from construction and road noise pollution as well as the defensive measures individuals may have privately undertaken to reduce these disamenities. Section 6.3 discusses these findings from the focus group discussions. Sections 6.4 and 6.5 reports the changes to the valuation questions and the background questions in response to the focus group discussions. These findings presented in Sections 6.4 and 6.5 inform the finalised design of the survey questionnaire. Section 6.6 reports the general feedback from the focus group discussion on the overall understandability of the survey questionnaires. The findings from the focus group discussions presented in this chapter provide information to improve the survey questionnaires thatin turn, seek to address the research questions presented in Chapter 3.

6.1 Focus group discussion protocols

The focus group discussion protocols for both the construction and road noise studies were broadly similar. The discussions comprised of four sections. The first section introduced the participant to the focus group discussion. Next, the participant's prior experiences with construction or road noise were elicited, followed by a section on the willingness-to-pay for noise abatement. Finally, participants were invited to complete a sample survey questionnaire and their feedback on the design of the questionnaire was collected. The discussions in the first three sections of the focus group discussion lasted for around 75 minutes while the completion of the sample survey questionnaire and subsequent discussions took around 45 minutes. The remainder of this section provides a discussion of the design of each part of the focus group discussion in detail.

6.1.1 Introduction and informed consent

The focus group discussions began with a brief introduction as to the purpose of the study and sought the informed consent of participants to participate in the discussion. Participants were presented with an information sheet detailing the aims of the study as well as the risks of participation. This information sheet included details on the aims of the survey, a brief description of the focus group discussion, as well as confidentiality and storage of data obtained from the discussion. The information sheet was approved by the ANU College of Asia and the Pacific's Delegated Ethics Review Committee. The moderator also reiterated to the participants that the discussions were recorded and that recorded construction or road noise would be played during the discussions. It was stressed that should participants voice any concerns related to the recording of the survey, it would be possible to stop the recording at any juncture. Similarly, if participants objected to being exposed to construction or road noise, they could leave the discussion at any juncture. After reviewing the information sheet, participants provided their written consent to participate in the focus group discussion.

Next, ground rules for the discussion were set by the moderator. These ground rules were designed to ensure that the views of all participants in the discussion were heard. Participants were reminded that everyone's opinions are important and were encouraged to contribute to the discussion. Further, participants were informed that their truthful responses would be valuable for the design of the survey. Lastly, participants were instructed to speak clearly and to turn off their mobile phones in order to ensure a conducive environment for the focus group discussions.

Participants were then invited to provide a brief introduction to themselves. As a segue to the next part of the discussion, participants were also asked about their homes, with a focus on whether they had experienced noise pollution at home.

6.1.2 Prior experiences with construction and road noise

This section of the focus group discussions broadly involved three topics. First, participants were asked about their experiences related to living near construction sites or roads. These disamenities included, among others, noise, dust and visual disamenities. Participants were asked to rank these disamenities based on the adverse effect on liveability at their homes. The discussions provided insight into the range of disamenities caused by construction activity and roads as well as the adverse impact of noise pollution in relation to other disamenities.

Next, the moderator focused the discussions on noise pollution. Participants were asked about the characteristics of construction and road noise that caused the most annoyance. Characteristics of noise can be categorised into the acoustic characteristics of the noise and non-acoustic characteristics of noise.

In order to facilitate the acoustic characteristics of noise in the focus group discussion, a series of recorded construction and road noise was played to participants. The recordings presented to participants are listed in Table 6-1. These recordings were all played to participants at 75dB.

Table 6-1 List of noise played to participants

	Source
Construction noise	
Demolition phase	
Recording 1	Actual recording from façade of nearest building
Recording 2	Actual recording from façade of nearest building
Foundation phase	Actual recording from façade of nearest building
Superstructure phase	Actual recording from façade of nearest building
Noise from specific equipment	
Recording 1	Recording of metal grinder
Recording 2	Recording of diesel engine
Recording 3	Recording of compressor
Road noise	
Expressway (free-flowing traffic)	Actual recording from façade of nearest building
Major road (free-flowing traffic)	Actual recording from façade of nearest building
Road Junction (Idling, start-stop traffic)	Actual recording from façade of nearest building
Bus stop (Idling, start-stop traffic)	Actual recording from façade of nearest building

The majority of noises presented to participants were obtained from actual recordings, with the exception of the recordings of specific construction equipment. In order to understand the annoyance caused by high-frequency noise, a recording of a metal grinder was included. Metal grinders are frequently used in the construction of a superstructure. However, as discussed in Section 2.5.2, absorption of high-frequency noise is higher relative to low-frequency noise, which causes low-frequency noise to dominate the actual recordings. The annoyance rating of the metal grinder as compared to the other noise recordings enabled a comparison of annoyance from high-frequency noise as compared to low-frequency noise. This comparison in turn provided information on how different frequencies affect annoyance. The sounds of two other pieces of equipment were also included, namely diesel engines and compressors. These pieces of equipment are frequently used during all phases of building construction.

For the road noise recording, recordings were chosen to represent different traffic conditions. Recordings from expressways and major roads sought to replicate the noise associated with free-flowing traffic. Both these roads had similar volumes of traffic. Noise was recorded from a road junction recording idling engine noise and the noise from vehicles accelerating and decelerating. Similarly, noise was recorded at a bus stop, picking up the acceleration and deceleration of buses.

After hearing the noise recordings, participants were asked to rank and rate their annoyance from each noise source. Participants were also asked to compare these recorded noises with their perceptions of actual construction and road noise. In particular, participants were asked whether these recordings accurately represented construction or road noise. The series of questions on recorded noise provided insights into whether the recordings were an accurate representation of construction and road noise.

Beyond the type of noise, participants were also asked about the loudness of noise they had experienced from construction activity and roads. Participants were asked whether the noise they had experienced was tolerable. Recordings of construction noise and road noise were played to participants at different loudness (i.e., 75, 70, 65, 60, and 55dB) and participants were asked to rate the annoyance of each loudness level. These ratings indicated how annoyance changed with reduction in noise levels.

Non-acoustic characteristics of noise include factors such as the time-of-day and day-of-week when noise is experienced. For construction activities, participants were asked about whether they preferred to have a shorter construction duration in exchange for louder construction noise. Responses to these questions informed the selection of attributes and levels for the choice model.

The final section in this part of the discussion involved asking participants about the steps they had taken to mitigate noise pollution within their homes. Examples of these measures could include installation of sound-proofing (e.g., double glazing of windows); closing the windows; leading to increased use of air-conditioning; use of earplug or noise cancelling headphones; and leaving the home when noise is excessive. Participants were also asked about the costs associated with implementing these measures. Asking about the costs of implementing noise mitigation measures privately served three purposes. First, the costs provided insights into the willingness-to-pay for implementation of noise abatement measures within the home. Second, the question sought to remind participants that noise mitigation is not costless since the next part of the discussion sought to understand the willingness-to-pay for noise pollution. Finally, the question reminded participants about the allocation of property rights to a quiet environment in Singapore. Specifically, if participants want to reduce noise levels to below the mandated levels, it is necessary to pay for the additional noise mitigation measures.

6.1.3 Willingness-to-pay for noise abatement

In the third part of the focus group discussions, the willingness-to-pay for noise abatement was discussed. A policy scenario was first presented to participants, outlining the steps that the government could take to reduce noise in Singapore. Payment vehicles to fund the implementation of the noise control policies were then discussed. Finally, for each payment vehicle, participants were asked about their willingness-to-pay for noise control.

6.1.3.1 Policy scenario

The policy scenario sets the context for the willingness-to-pay questions which followed. Participants were informed that the government is considering the implementation of politics to decrease the level of noise from construction sites or roads in Singapore by mandating more stringent noise control.

In order to understand the participants’ views on the levels and attributes in the choice set, a range of policies to mitigate the adverse effects of noise were presented to participants. These mitigation measures are outlined in Table 6-2.

Table 6-2 List of proposed mitigation measures to reduce noise from construction sites and roads

Type of noise mitigation	Construction noise	Road noise
Noise reduction at source	Mandating the use of quieter construction equipment	Mandating that vehicles meet more stringent noise emission standards
	Disallowing construction work at different times-of-day	Mandating the use of quiet paving materials for road construction
	Disallowing construction work at different days-of-week (e.g., weekends)	Restricting the maximum speed of vehicles
	Disallowing construction work at during public holidays	
	Mandating changes to duration of construction activity	
Noise reduction along the sound path	Blocking noise along the sound path with noise barriers	Blocking noise along the sound path with noise barriers
Noise reduction at the receptor	Retrofit homes with sound-proofing measures (e.g., double glazing of windows)	Retrofit homes with sound-proofing measures (e.g., double glazing of windows)

Participants were informed that these noise mitigation policies are effective over different areas. Specifically, noise reduction at the source affects all areas that are adversely affected by the noise. For instance, if construction activity is prohibited on weekends, then residents will not be affected by construction noise on weekends. However, if the noise reduction measure is sound-proofing within the home, then only residences will experience reduced noise levels. Consequently, participants were reminded that noise reductions at the source and along the sound paths are publicly-provided noise reduction, while noise reduction at the receptor is akin to private provision of noise abatement.

Following the introduction of these policy measures, participants were asked whether they thought that these measures could lead to effective noise abatement and whether they needed more information about each policy measure. Participants also discussed their preferences for each policy measure and whether there were other measures that could be implemented to reduce the adverse effects of noise pollution. Responses to this part of the discussion provided information on the phrasing of the policy scenario presented to participants of the choice modelling survey.

6.1.3.2 Payment vehicles

Next, participants were informed that the policies implemented by the government are costly. Consequently, participants were asked whether they would be willing to pay for noise abatement measures. Participants were reminded that in the previous section of the focus group discussion, some participants made private investments in the reduction of noise in their homes. Consequently, pooling of funds for the government to implement noise abatement measures could potentially lower the costs of private investment into noise abatement.

As discussed in Section 5.5, a credible and compulsory payment vehicle must be presented to participants of the choice modelling survey in order for participants to state their true willingness-to-pay. As such, the range of payment vehicles discussed in Section 5.5, namely taxes, maintenance charges and community funds, were presented to the focus group discussion participants. Participants were asked about their preferences for each payment vehicle. Further, participants also discussed their preferences for frequency of contributions to these payment vehicles. For instance, the contribution to each payment vehicle could be monthly, annual, or one-off. Participants were also invited to suggest other payment vehicles.

6.1.3.3 Willingness-to-pay for noise abatement

After the discussion on payment vehicles, participants were asked about their willingness-to-pay for the provision of noise abatement by the government. The moderator asked each participant to record the highest amount that they were willing to pay for each payment vehicle previously discussed. After participants had written down their willingness-to-pay, the moderator asked each participant to reveal their stated willingness-to-pay. Participants were then asked to discuss the reasons for their willingness-to-pay, particularly among participants with low willingness-to-pay or very high willingness-to-pay. Variations of willingness-to-pay between different payment vehicles and frequency of payment were also discussed.

In order to understand the willingness-to-pay for attributes other than noise, participants were asked to discuss factors that could affect their willingness-to-pay. Examples of these factors in the construction noise context could include the duration of construction activity, the time-of-day when construction is permitted, and the effect of different construction phases on willingness-to-pay. For the road noise focus group discussions, examples of factors that could affect willingness-to-pay include time-of-day when road noise is experienced and the effect of different policy measures on the willingness-to-pay.

6.1.4 Sample survey questionnaire

Finally, in the last part of the discussion participants completed a sample survey questionnaire. This section of the focus group discussion sought to gain an understanding of whether the survey questionnaire provided sufficient information for participants to make an informed decision when answering the questions.

In order to establish the consequentiality of the survey, participants were informed that the survey was conducted on behalf of the government. They were told that the results of the survey would be used to inform future policies related to regulation and control of noise in Singapore. Hence, the participant's assistance was sought to review the survey questionnaire and provide their honest opinions on the design of the survey. Given the novel design of the survey questionnaire, which presented recorded noise to participants in the choice set, the focus group discussions were also a trial-run of the main survey. Hence, any technical problems with the survey questionnaire could be rectified before proceeding to the next phase of the survey.

Similar to the survey in later phases, each participant completed the survey questionnaire with a Samsung Galaxy Tab 5 connected to a pair of Audio Technica M40x headphones. While participants completed the survey questionnaire, they filled in a feedback form asking whether they understood the various parts of the survey.

Participants were given around 20 to 30 minutes to complete the survey before proceeding to a discussion on the design of the survey. Discussions began with questions regarding the survey in general. Participants were asked whether the information provided in the survey was clear and readily understandable. Since the survey questionnaire presented participants with a series of recordings of annoying noises, participants were asked whether the length of the survey was acceptable as well as whether the noise presented was excessive in terms of length and loudness.

Specific to the choice modelling section, participants were asked whether the proposed policy scenario in the draft survey questionnaire was clear and whether they understood that they should consider all attributes when making their choices in each choice set. Participants were then asked about the representativeness of the recorded noise used in the survey questionnaires and whether the recorded noises resemble actual noises as well as whether the loudness of the recorded noises was similar to noises that participants had experienced. Participants were also asked whether they could perceive the differences between the various noise recordings.

Next, participants' views on the hearing acuity test questions[54] were sought. Participants were asked whether they understood that they should click on the survey questionnaire when they could not hear the test tone during the descending test and that they should click when they just hear the test tone during the ascending test. Participants were also

[54] Refer to Section 5.9.2 for a discussion on the protocol for the hearing acuity test

asked whether the test tones in the hearing acuity test was sufficiently long so that they were able to respond.

Finally, the moderator concluded the focus group discussion by asking participants whether they had any final comments on the effect of noise on residents and whether they had any other feedback on the survey questionnaire.

6.2 Sampling frame and logistics of the focus group discussions

Participants in the focus group discussions were recruited through a panel of participants from the survey company's database. The survey company sent emails to members of the panel and interested participants were asked to respond. There were either nine or ten participants in each focus group discussion. In total, 38 and 18 participants participated in the focus group discussions for construction and road noise respectively. The demographic details of the participants in each of the focus group discussions are presented in Table 6-3.

Table 6-3 Demographic details of participants in focus group discussions

	Construction noise					Road noise		
Session	FGD 1	FGD 2	FGD 3	FGD 4	Overall	FGD 1	FGD 2	Overall
Median age (Years)	30	39	49	58	44.5	32	39	34.5
Proportion of females	0.44	0.50	0.44	0.50	0.47	0.44	0.56	0.50
Racial representation								
Chinese	0.56	0.50	0.56	0.60	0.55	0.67	0.67	0.67
Malay	0.33	0.20	0.11	0.20	0.21	0.22	0.33	0.28
Indian	0.11	0.30	0.33	0.20	0.24	0.11	0	0.06
Number of participants	9	10	9	10	38	9	9	18

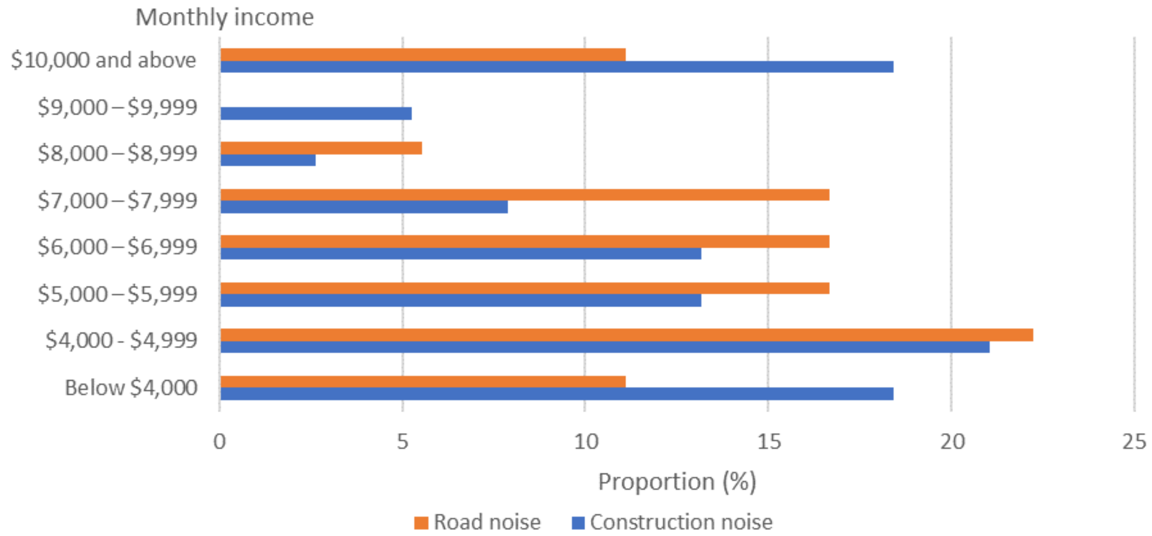
Note: Overall median age refers to the median age across all participants in the construction noise and road noise focus group discussions. The proportion of females is the number of females divided by the total number of participants in each discussion. The overall proportion of females is the total number of females divided by the total number of participants in the construction noise and road noise focus group discussions. Racial representation refers to the proportion of each race in each session.

The focus group participants were selected for each session based on their age. Prior experience by the survey company with focus group discussions conducted in Singapore, showed that participants tended to share their views more readily when they with their peers. Consequently, where possible, participants of around the same age band were chosen for each focus group discussion session. Nonetheless, across the six focus group sessions, participants from a broad range of ages participated in the discussions. For the focus group discussions for construction noise, age of participants ranged from 23 to 72. For road noise, the age of participants ranged from 20 to 60.

The gender and racial distribution of participants in the focus group discussions also broadly covered all demographic profiles of citizens and permanent residents in Singapore. The male and female representation was approximately equal across all focus group discussion sessions. Chinese representation was highest, as approximately three-quarters of Singaporeans are Chinese (Statistics Singapore 2018d). Nonetheless, the minority races, namely Malay and Indian, were also represented in most focus group discussion sessions.

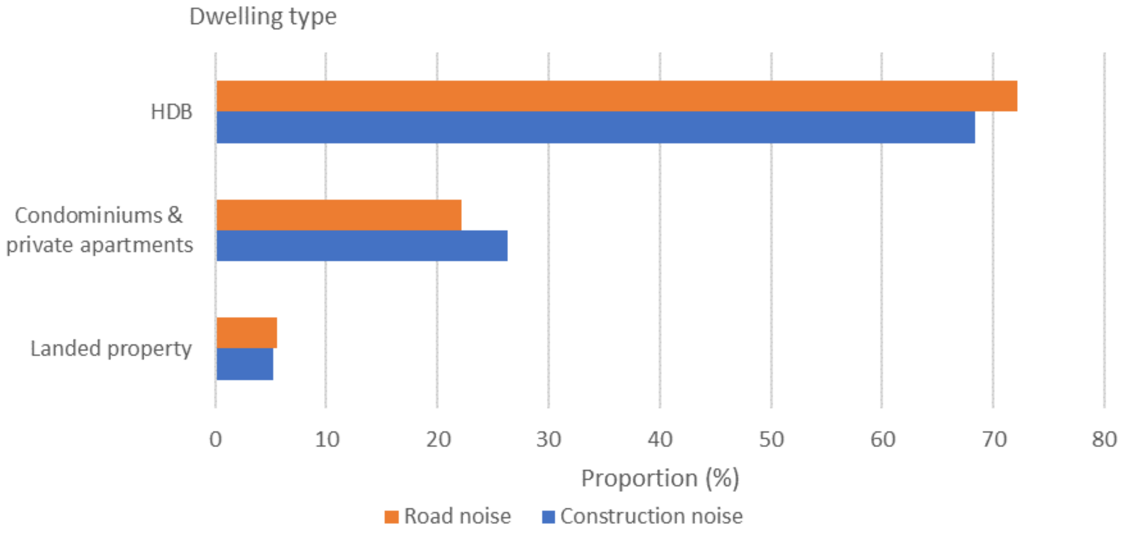
Participants in the focus group discussions also came from a wide range of socio-economic backgrounds. The income distribution of the focus group discussion participants is presented in Figure 6-1. Average monthly household incomes of participants ranged from below S$4,000 to above S$10,000. By comparison, the 20th decile of household income in Singapore was S$3,930, while the 60th decile of household income was S$10,973 (Statistics Singapore 2018a).

Figure 6-1 Distribution of self-reported average household income among focus group discussion participants



The dwelling type of focus group discussion participants are shown in Figure 6-2. The distribution of participant's dwelling type is similar to Singapore's overall housing situation. In Singapore, around 80% of residents live in public housing developed by the Housing Development Board (HDB), with the remainder living in private properties (HDB 2017). By comparison, in the focus group discussions around 70% of participants lived in public housing and the remainder lived in private housing, such as condominiums, apartments, and landed properties.

Figure 6-2 Dwelling type of focus group discussion participants



6.3 Findings from focus group discussions

This section outlines the findings from the focus group discussions. The survey questionnaires were amended to take into account these findings. These changes to the survey questionnaire are also outlined in this section.

6.3.1 Annoyances arising from construction activity

In line with the high density of construction sites[55] in Singapore, almost all focus group discussion participants were currently living near a construction site or have previously lived near a construction site. In total, only three participants had not experienced living near construction sites.

Disamenities associated with living near construction sites were well known to participants. Several participants had actively attempted to purchase property situated away from existing and potential construction sites. For instance, a participant purchased a home surrounded by completed buildings to avoid construction sites. Nonetheless, participants agreed that it was difficult to predict future construction sites due to the prevalence of construction activity in Singapore.

Among the disamenities caused by construction activity, noise pollution was spontaneously mentioned by almost all participants. Noise pollution from construction activity adversely affected sleep and rest, particularly among participants who work on the night shift

[55] In 2015, there were around 5,900 active construction sites in Singapore (Tay 2015), and on average, there are around 8 construction sites per square kilometre of land area.

(and therefore rest in the day), as well as home-makers with babies and young children. Noise also disrupted the quiet environment within the home, affecting both leisure activities (e.g., watching TV) and working from home. Communication with other members of the family is also adversely affected, particularly with elderly folk. Noise pollution also affected participants' mental well-being. Consequently, participants experienced higher levels of stress and irritation as well as shorter tempers. A related disamenity was the vibration caused by construction equipment if homes were in close proximity to the construction site.

Other disamenities caused by construction noise included dust, safety and inconvenience due to traffic diversions. Dust was the second most mentioned disamenity from construction activity. The increased level of dust from construction sites necessitated more regular cleaning of the house as well as the need to close windows and doors to reduce dust within the house. Participants also raised safety concerns from the heavy vehicles travelling to the construction site. Drivers of these vehicles were perceived to have lower visibility than cars and other vehicles and participants were concerned that pedestrian safety may be compromised. Relatedly, the increased heavy vehicle traffic caused increased traffic congestion and travelling times due to road diversions or pedestrian path detours.

Focusing on the characteristics of noise, participants were more adversely affected by construction noise on weekends as compared to weekdays. As described in Section 5.6.1, construction activity is prohibited on Sundays and Public Holidays. However, the majority of Singaporeans worked for five days in a week. Consequently, construction noise on Saturdays was found to be particularly annoying.

Construction noise at different times-of-day had heterogeneous effects on participants, depending on their employment and lifestyle habits. Individuals who left the house on a regular basis (e.g., employees who travel to their workplaces) were less affected by noise in the day when they were at work. However, these participants were particularly annoyed by noise experienced in the morning and evenings when they were at home. These participants preferred to have a quiet environment at home after spending the entire day at work. In contrast to employed individuals, participants who spent the majority of time at home (e.g., home-makers and retirees) found noise at all times of day to be annoying.

The annoyance associated with different construction noise was also ranked and rated by participants. The results of participant's ratings are summarised in the table below.

Table 6-4 Average annoyance rating associated with construction noise

	Noise source	Rating
Demolition phase		
Recording 1	Actual recording from façade of nearest building	6.8
Recording 2	Actual recording from façade of nearest building	6.9
Foundation phase	Actual recording from façade of nearest building	6.6
Superstructure phase	Actual recording from façade of nearest building	6.9
Noise from specific equipment		
Recording 1	Recording of metal grinder	8.2
Recording 2	Recording of diesel engine	6.4
Recording 3	Recording of compressor	6.9

Note: Participants were asked to rate each noise, with one being least annoying and ten being most annoying.

Among the noises which were recorded from the nearest building, the average annoyance rating ranged from 6.6 to 6.9. The ratings indicate that these sounds caused around the same level of annoyance for participants. The responses corroborated the proposition made in Section 5.6.1 that low-frequency noise tended to dominate when the noise is heard at a distance from the source. Further, these low-frequency noise recordings caused a similar level of annoyance among participants.

The noise that caused the most annoyance and had the highest annoyance rating was the recording of the metal grinder. Unlike other recordings, the high-frequency noise components of this recording were louder, which contributed to the increased annoyance with this noise as compared to other recordings which were predominately low-frequency noise.

The average annoyance rating of the general sources of noise range from 6.4 to 6.9, broadly similar to the annoyance rating of the noises that were recorded from the nearest buildings. Participants were less annoyed by these pieces of equipment as compared to the metal grinder as the engine and compressor generated predominantly low-frequency noise, similar to the noise recordings obtained from the façade of the nearest building.

Participants were also asked to provide the annoyance rating for construction noise played at different levels of loudness. The average annoyance ratings associated with the different loudness of construction noise are presented in Table 6-5. The results suggest that a 10dB decrease in noise levels was approximately correlated with a halving of the annoyance rating. These results were in line with the other studies in the psychoacoustics literature, which finds that a 10dB increase in noise levels corresponded to halving the perceived loudness of sounds (Fastl & Zwicker 2007).

Table 6-5 Average annoyance rating associated with different sound pressure levels of construction noise

Loudness (dB)	Rating
75	6.8
70	4.4
65	3.6
60	1.7
55	1.2
50	1.0

Note: Participants were asked to rate each noise, with one being least annoying and ten being most annoying. The construction noise presented to participants was Recoding 1 of the demolition phase.

When participants were asked about whether the noise recordings they heard resembled construction noise, most participants agreed. Participants were also able to identify the equipment associated with recordings of specific equipment (i.e, metal grinder, diesel engine and compressor). Participants were also asked whether the noise recordings, when played at 75dB, were as loud as the noise they have experienced. Some respondents indicated that the noise recordings were quieter than actual construction noise experienced in their homes. However, to safeguard respondents' hearing, the maximum noise levels were fixed at 75dB.

Participants were also asked about the duration of construction activity near their homes and whether they preferred more intensive construction activity in exchange for shorter construction duration. Around two-thirds of participants preferred more intensive construction activity if the construction activity was shortened by at least six months. There appeared to be heterogeneity in the preference for more intense construction activity. Individuals who were employed indicate that they will likely be at work when the construction activity is occurring and will benefit from a reduction of the overall duration of construction activity. Further, if construction is sufficiently reduced, alternative arrangements could be made to avoid the noise (e.g., leaving for extended holidays or staying at parent's homes). However, home-makers or families with children preferred long durations with less intense construction activity as they were directly affected by the increase in disamenities from construction activities.

Finally, participants' views on the type of publicly-provided noise abatement measures were sought. The majority of participants supported publicly-provided noise abatement that mandates the reduction of noise emissions from construction companies. For instance, participants suggested that the government can mandate that construction companies use quieter construction equipment. A minority of participants also suggested that the government could subsidise the retrofitting of noise abatement measures within homes (e.g., installation of double glazed windows). These participants indicated that publicly-provided retrofitting of homes could increase home values. However, since construction sites are temporary, most participants thought that the inconvenience arising from retrofitting homes would not outweigh the benefits of implementing these measures.

6.3.2 Annoyances arising from roads

The experiences of the participants in the road noise focus group discussions were similar to those of the construction noise survey. Almost all road noise focus group discussion participants had current or prior experience living near a road. The experience of these participants reflected the high density of roads in Singapore, where almost all buildings are connected to a paved road and 12% of Singapore’s land area is dedicated to roads (MOT 2017).

Participants cited noise as being a key source of disamenity from living near roads. Road noise caused a litany of difficulties for residents. First, participants said that they experienced interrupted sleep, particularly when there are sudden spikes in noise levels (e.g., noise from sportscars or motorcycles with modified mufflers or horns from vehicles). Second, road noise adversely affected entertainment and leisure activities. For instance, participants reported difficulty hearing when watching television. Third, the increased levels of noise also caused difficulties when communicating with members of the family. Fourth, families with children said that the noise was disruptive to the child’s learning as it was difficult to communicate with the child due to the increased noise levels.

When participants were asked if road noise had different effects at different times-of-day, participants replied that the annoyance caused by road noise was effectively constant. During the peak-hours in the morning and evenings, heavy traffic led to increased levels of noise. In the night, while traffic is less heavy, the quieter surroundings cause road noise to be more prominently perceived. Further, vehicles tend to travel more quickly at night, leading to increased noise level, particularly if the exhaust mufflers of the vehicles have been modified by the vehicle owner.

Participants were then played a series of recorded road noise and were asked to rate the annoyance associated with each noise. The ratings are presented in the table below.

Table 6-6 Average annoyance rating associated with road noise

	Type of noise	**Rating**
Expressway	Free-flowing traffic	6.9
Major road	Free-flowing traffic	7.3
Road Junction	Idling traffic	5.8
Bus stop	Idling traffic	5.4

Note: Participants were asked to rate each noise, with 1 being least annoying and 10 being most annoying. Recordings were all taken from the façade of the nearest building.

The average annoyance ratings were 6.9 and 7.3 for free-flowing traffic recorded at expressways and major roads respectively. At road junctions and bus stops, the annoyance ratings were 5.8 and 5.4 respectively. Noise recordings for road noise were the most annoying as they included horns from vehicles during the recordings. Further, noise from expressways was perceived to be predominantly wind noise arising from vehicles travelling at high speed. The noise recordings from free-flowing traffic appeared to cause more annoyance as compared to idling traffic at road junctions and bus stops because there were intervals of quieter sounds with idling traffic. However, a minority of participants, particularly those living near road junctions or bus stops, reported that idling traffic causes more annoyance as compared to free-flowing traffic. These participants said that the noises of accelerating and decelerating vehicles were particularly irritating.

Participants were then asked to rate the annoyance caused by different loudness of road noise. The ratings are presented in the table below. Similar to the results from the construction noise focus group discussions, a 10dB decrease in noise levels was approximately correlated with a halving of the annoyance rating.

Table 6-7 Average annoyance rating associated with different sound pressure levels of road noise

Loudness (dB)	Rating
75	6.9
70	4.4
65	3.6
60	1.7
55	1.2
50	1.0

Note: Participants were asked to rate each noise, with 1 being least annoying and 10 being most annoying. Recordings presented to participants was recorded at the expressway.

When participants were asked whether the noise recordings were similar to actual road noise, most participants agreed. However, the noise that participants experienced at home was louder than the noise played at 75dB during the focus group discussion, particularly among participants who live near expressways. While actual road noise was louder than 75dB, the noise recordings were capped at 75dB to protect the hearing of survey respondents.

Unlike construction noise, annoyance due to road noise persisted throughout the day. In the day, high volume traffic causes engine noise to dominant, while wind noise dominants at night due to fewer cars driving more quickly.

When participants were asked about the abatement measures to reduce construction noise, a wide range of abatement measures were suggested. Unlike construction noise, which will only occur over the duration of the construction activity, road noise was permanent. As such, participants suggested the implementation of more permanent solutions. Examples of abatement measures include building noise barriers along roads, repaving road surfaces, and tightening vehicular noise emission regulations. Participants also indicated that publicly-provided retrofitting of their homes with noise abatement measures was an option as road noise was a permanent source of noise pollution.

6.3.3 Private provision of noise mitigation measures

Most participants said that they have implemented private noise abatement measures in response to the elevated levels of noise caused by construction activity and roads. Among these privately-provided noise abatement measures, the most commonly cited abatement measure was the closing of windows and doors to reduce the impact of noise. Due to Singapore's tropical climate, participants also tended to use the air-conditioning more often when they close their windows and doors.

Some participants invested in measures to further reduce the noise after closing windows and doors. For example, a participant installed noise insulation rubber along window seams. Other participants retrofitted their windows with double glazed windows. Participants have also installed thicker curtains to reduce the impact of noise. Participants living near roads, which is a permanent source of noise as compared to construction activity, were more likely to invest in these measures to reduce noise.

Some participants also purchased earphone and headsets so that they do not hear the noise. Some participants wore earplugs when going to sleep. Some older participants said that they will increase the volume from entertainment devices (such as televisions and radios) such that the sound from these devices is louder than the noise from construction activity or roads.

Some participants indicated that they left their homes when the noise from construction activity or roads become too loud. Some participants spent time at nearby malls in order to avoid the noise at home. Other participants visited their relatives' or friends' homes. A few participants also discussed the possibility of shifting to their relatives' homes or purchasing a new property as a longer-term goal in order to avoid noise.

The costs of implementing these abatement measures varied depending on the abatement measure. Participants estimated that they spent around S$5 to S$200 of private expenditure as a result of noise. However, this expenditure included the benefits associated with the privately-provided abatement measures. For example, if an individual shopped at a mall, the amount spent at the mall cannot be solely attributable to noise. Similarly, turning on the air-conditioning increases comfort within the resident's homes by lowering temperature in addition to reducing the loudness of noise at the home. Consequently, respondents opined that it was difficult to estimate the amount which they spent on privately-provided noise abatement.

6.4 Refinements to the valuation questions

The focus group discussions provided insights into the improvements that can be made to the valuation questions. The responses from the participants related to each part of the valuation questions are summarised in turn.

6.4.1 Policy context to mitigate noise

Participants agreed that the policy context drafted in Section 5.3 (also shown in Table 6-8) was representative of Singapore's situation. The participants said that they understood the policy context and that the information provided in the policy context was in line with their experiences of living in Singapore. As such, the surveys used the policy context presented in Table 6-8 to frame the choice sets presented to survey respondents.

Table 6-8 Policy context presented to participants of focused group discussions

<u>Construction noise survey</u> Singapore is geographically small, highly urbanised and densely populated. The rapid pace of development has led to a high number of construction sites in Singapore. However, residents living near construction sites may be affected by higher levels of noise. <u>Road noise survey</u> In order to ensure that everyone in Singapore can conveniently travel to other parts of Singapore, the Government has built a network of roads and expressways. However, residents living near these roads may experience higher levels of noise.

6.4.2 Payment vehicles

Since no existing payment vehicle exists for respondents to fund publicly-provided noise abatement, participants provided a wide range of suggestions for possible payment vehicles. These vehicles are discussed in turn.

The most popular payment vehicle suggested by participants was the diverting of public funds from other public amenities to the funding of publicly-provided noise abatement. For instance, the government could reduce expenditure on amenities, such as parks or playgrounds, and spend more on publicly-provided noise abatement. Participants preferred this payment vehicle as there was no out-of-pocket expenditure on their part. While popular vehicle, this vehicle does not provide an accurate estimate of the marginal benefits of publicly provided noise abatement. Since this payment vehicle does not require survey respondents to pay for the publicly-provided noise abatement from their own pockets, participants can potentially report a willingness-to-pay higher than their actual willingness-to-pay. Further, in this payment vehicle, survey respondents are trading-off the marginal benefits associated with one public good (e.g., the amenities from parks) against another public good (i.e., publicly-provided noise abatement). Since the marginal benefits associated with the provision of parks or playgrounds are not known, it would be difficult to estimate the marginal benefits of noise abatement.

Participants also suggested that funds from the respondent's Central Provident Fund (CPF) be used to fund publicly-provided noise abatement. The CPF is a savings scheme mandated by the Singapore government to set aside funds for retirement. In general, the funds in an individual's CPF can only be accessed after the individual retires and is not generally regarded as a component of an individual's income. Consequently, use of this payment vehicle proposes a transfer of future retirement to fund present consumption in the form of provision of noise abatement. Hence, survey respondents will likely overstate the willingness-to-pay for publicly-provided noise abatement as respondents valued funds in the CPF less than their out-of-pocket savings.

Co-funding of the abatement measures by the government was also suggested as a payment vehicle. For instance, the government could match dollar-for-dollar the payment by individuals. Similar to other suggested payment vehicles, co-funding by the government does not elicit the true willingness-to-pay for noise abatement. Since the government would be co-funding the measures, participants could freeride on the payment vehicle and some participants reported a lower willingness-to-pay since their out-of-pocket expense is lower. As such, while this payment may result in fewer protest votes, the estimated marginal benefits will likely be under-estimated.

Since the payment vehicles suggested by participants may lead to inaccurate estimates of the marginal benefits of publicly-provided noise abatement, participants' views on the payment vehicles suggested in Section 5.5 were also sought. Among taxes, service and conservancy charges (S&CC), and mandatory contribution to a community fund, participants preferred the mandatory contribution to a community fund. Participants indicated that they believed that community funds were more likely to be ring-fenced for noise abatement measures as compared to an increase in taxes and S&CC. In the participants' opinion, community funds were seen as being separate from the government revenue and the community fund is more unlikely to be used for other purposes beyond funding noise abatement. Consequently, this payment vehicle achieved the most support among respondents.

In contrast to community funds, taxes were viewed more unfavourably by respondents. Participants were generally sceptical that increases in taxes could lead to increased noise abatement, particularly since they claim that they are already paying tax and are still adversely affected by noise pollution. Further, participants opined that taxes can be used for any purpose and the government may not use increased tax revenue to provide additional noise abatement.

Similar, participants did not favour the use of S&CC as the payment vehicle. In Singapore, S&CC is paid to the Town Council, which is managed by the ruling political party in that estate. However, the majority of electoral districts in Singapore are held by the People's Action Party, which also forms the government. Consequently, most participants viewed S&CC as another form of taxation. Further, participants indicated that the S&CC was used for a variety of purposes and increased S&CC payment may not translate to increased implementation of noise abatement measures.

For contribution to a community fund, S&CC and taxes, participants were also asked about their preferences on the interval between payment. Participants did not favour monthly payment as they felt that monthly payment necessitated effort to pay for the contributions each month. For some participants, this effort involves having to remember to pay for the bills. Other participants, particularly among older participants indicated that they would have to expend time to pay for the contributions physically. Consequently, participants said that they preferred the payment be made annually or as a one-off.

There were benefits associated with annual and one-off payment intervals. On the one hand, participants said that an annual payment will likely be less substantial as compared to a one-off payment, enabling participants to spread their payments over time. However, participants also indicated that a one-off payment required less effort to comply with since participants only had to pay once. As such, participants did not reach a consensus on which payment interval was preferred.

Participants were also asked about whether they preferred the payments to be made at the household- or individual-level. Some participants said that they did not know the preferences of their household. For example, younger respondents who were not the head of their households indicated that they could not speak for the preferences of their household. Hence, the payment vehicle asked about willingness-to-pay at the individual level.

Participants were asked about the maximum value they were willing to contribute to completely remove the adverse effects of noise abatement. These values were stated for different payment vehicles (i.e., contribution to a community fund, S&CC and taxes), and for different payment intervals (i.e., annual and one-off contributions). Summary statistics of participant's responses in the construction and road noise surveys are shown in Table 6-9 and Table 6-10 respectively.

Table 6-9 Willingness-to-pay for construction noise abatement

Payment Vehicle	Willingness-to-pay (S$)
Contribution to a community fund (annual contribution)	Average: 32 Minimum: 5 Maximum: 175
Contribution to a community fund (one-off contribution)	Average: 87 Minimum: 10 Maximum: 250
S&CC (annual contribution)	Average: 12 Minimum: 0 Maximum: 30
S&CC (one-off contribution)	Average: 37 Minimum: 0 Maximum: 75
Taxes (annual contribution)	Average: 9 Minimum: 0 Maximum: 25
Taxes (one-off contribution)	Average: 22 Minimum: 0 Maximum: 60

Table 6-10 Willingness-to-pay for road noise abatement

Payment Vehicle	Willingness-to-pay (S$)
Contribution to a community fund (annual contribution)	Average: 92 Minimum: 15 Maximum: 240
Contribution to a community fund (one-off contribution)	Average: 237 Minimum: 50 Maximum: 500
S&CC (annual contribution)	Average: 36 Minimum: 0 Maximum: 75
S&CC (one-off contribution)	Average: 158 Minimum: 0 Maximum: 250
Taxes (annual contribution)	Average: 27 Minimum: 0 Maximum: 60
Taxes (one-off contribution)	Average: 62 Minimum: 0 Maximum: 150

Overall, participants in the road noise focus group discussions expressed a higher willingness-to-pay as compared to participants in the construction noise focus group discussions. Participants in the construction noise focus group discussion indicated that a key factor affecting their willingness-to-pay was the temporary nature of construction activity. Summary statistics also indicated that a contribution to a community fund yielded the highest willingness-to-pay, which is in line with participants views that a contribution to a community fund was most likely to result in increased provision of noise abatement.

Participants' stated willingness-to-pay for an annual contribution was also lower as compared to a one-off contribution. This was expected as a one-off contribution is the present value of a stream of annual payments. If participants considered their discount rates and the annual payment over time, then use of one-off contribution and annual payment will yield the same willingness-to-pay. Conversion between these two payment vehicles involves annualising the one-off contributing or computing the present value of the annual payment, both of which will be equivalent. However, participants may be myopic and value current expenditure more highly. In this case, a one-off contribution may understate the participant's willingness-to-pay, since they will be discounting future values more than their actual discount rate. By contrast, an annual contribution may overstate the participant's willingness-to-pay. Participants are making a decision at the present period on whether they would like to pay for noise abatement in future periods. Consequently, they may not consider the costs they have to bear in future periods if an annual payment was used. Both intervals were tested in the pilot phase of the field survey in order to estimate the differential effect of differing payment intervals.

6.4.3 List of attributes and levels

The focus group discussion provided insights into the list of attributes used in the design of the choice set. The levels associated with each of these attributes were also refined based on the discussions in the focus group discussions. The attributes and levels for the construction noise and road noise survey are discussed in turn in the remainder of this section.

6.4.3.1 Attributes for construction noise survey

Following the construction noise focus group discussions, the revised attributes and levels for the construction noise choice modelling survey questionnaire are presented in Table 6-11. As discussed in Section 6.3.1, while some participants found that the maximum loudness of 75dB was quieter than the construction noise they experienced at their homes, the loudness was capped at 75dB. Participants also agreed that changes to the times when construction activity is permitted could reduce annoyance. These times include days when construction activity is prohibited as well as the time-of-day when construction activity is permitted to start and mandated to end. Finally, participants were willing to trade off the duration of construction activity and the loudness of construction noise. Hence, the duration of construction activity was also included as an attribute. Lastly, the highest level of the costs attribute was set based on the maximum stated willingness-to-pay in the focus group discussion.

Table 6-11 Candidate attribute and levels for construction noise survey

Attribute	Levels
Loudness of construction noise (dB)	**75**; 70; 65; 60; 55
Days where construction activity is prohibited	**Sundays and public holidays only**; Saturdays, Sundays and public holidays only; Saturdays, Sundays, public holidays and eve of public holidays
Time when construction is permitted to start	**7am**; 9am; 10am; 11am
Time when construction is mandated to end	**7pm**; 6pm; 4pm; 3pm
Duration of construction activity	12 months less; 6 months less; **No change**; 6 months more; 12 months more
Cost (S$)	**0**; 50; 100; 150; 200; 250

Note: Levels are separated by semi-colons. Baseline alternatives are bolded.

6.4.3.2 Attributes for road noise survey

Unlike the construction noise survey, participants in the road noise survey seemed to be equally annoyed by road noise at all times of the day. Further, there are no practical measures to reduce road noise at certain times of the day. Consequently, the attributes in the road noise survey were the level of noise from roads as well as the publicly-provided mitigation measures and the costs of providing these measures. Similar to construction noise, most participants said that the loudness of road noise was quieter than that experienced at their homes. However, the maximum loudness was set at 75dB to protect the hearing of survey respondents. Measures to reduce road noise were based on suggestions by respondents and consultation with officials at the Land Transport Authority revealed that these measures were being considered for implementation. Finally, the maximum level for the cost attribute was determined based on the maximum reported willingness-to-pay in the focus group discussion.

Table 6-12 Candidate attribute and levels for road noise survey

Attribute	Levels
Loudness of road noise (dB)	**75**; 70; 65; 60; 55
Noise reduction measure	**None**; Installation of noise barriers near roads; Construction of roads with low-noise surfaces; Installation of sound-proofing within the house of the resident; Tightening the enforcement of regulations on vehicular noise emissions
Cost (S$)	**0**; 100; 200; 300; 400; 500

Note: Levels are separated by semi-colons. Baseline alternatives are bolded.

6.4.4 Experimental designs

The total number of combinations of alternatives and levels described in the previous section is large. For example, in the construction noise survey, there are six attributes with each attributes having between three and six levels. As a result, there are around 7,200 combinations of levels with the candidate set of attributes and levels. Consequently, it is not possible to present survey respondents with a full set of alternatives as respondents cannot feasibly answer such a number of questions.

In order to reduce the number of alternatives presented to each participant, experiment design methods are employed to select a subset of combinations from all combinations (Bliemer & Collins 2016; Hoyos 2010; Scarpa & Rose 2008). Various types of experimental design have been proposed, the most common being orthogonal designs (Hensher, Rose & Greene 2015; Scarpa & Rose 2008). An orthogonal design searches for a subset of choices by assuming that the correlation between attributes is zero. While an orthogonal design requires less computation, such a design is not efficient as it requires larger samples to produce reliable parameter estimates as compared to efficient design (Rose & Bliemer 2009).

A key shortcoming of orthogonal designs is that they determine independent effects in linear models. However, as discussed in Section 4.1, the econometric models used to analyse choice models are typically not linear (e.g., the conditional logit model). Consequently, efficient design of choice sets seeks to minimise the variance from the regression model. In other words, an efficient design seeks to choose the set of levels and attributes in each alternative j in choice scenarios s, denoted x_{sj}, which minimises an error criterion. There are several criteria for this minimisation, including the D-error and the A-error (Scarpa & Rose 2008). The formulae for these errors are:

$$D - error = \det\left(\Omega(\beta, x_{sj})\right)^{1/K} \quad (5–16)$$

$$A - error = \text{trace}\left(\Omega(\beta, x_{sj})\right) \quad (5–17)$$

where $\Omega(\cdot)$ is the asymptotic variance-covariance matrix, which is equivalent to the negative inverse of the second derivative of the log-likelihood function (McFadden 1974). For the D-error, $\det(\cdot)$ refers to the determinant. Since the determinant increases as the number of estimation parameters, β, increases, the D-error is scaled by the K number of β in a model. For the A-error, $\text{trace}(\cdot)$ refers to the trace of the asymptotic variance-covariance matrix. In the literature, the D-error is more commonly used as the A-error does not account for off-diagonals in the asymptotic variance-covariance matrix, potentially leading to covariances in parameters (Scarpa & Rose 2008). As such, the D-error is used in this research.

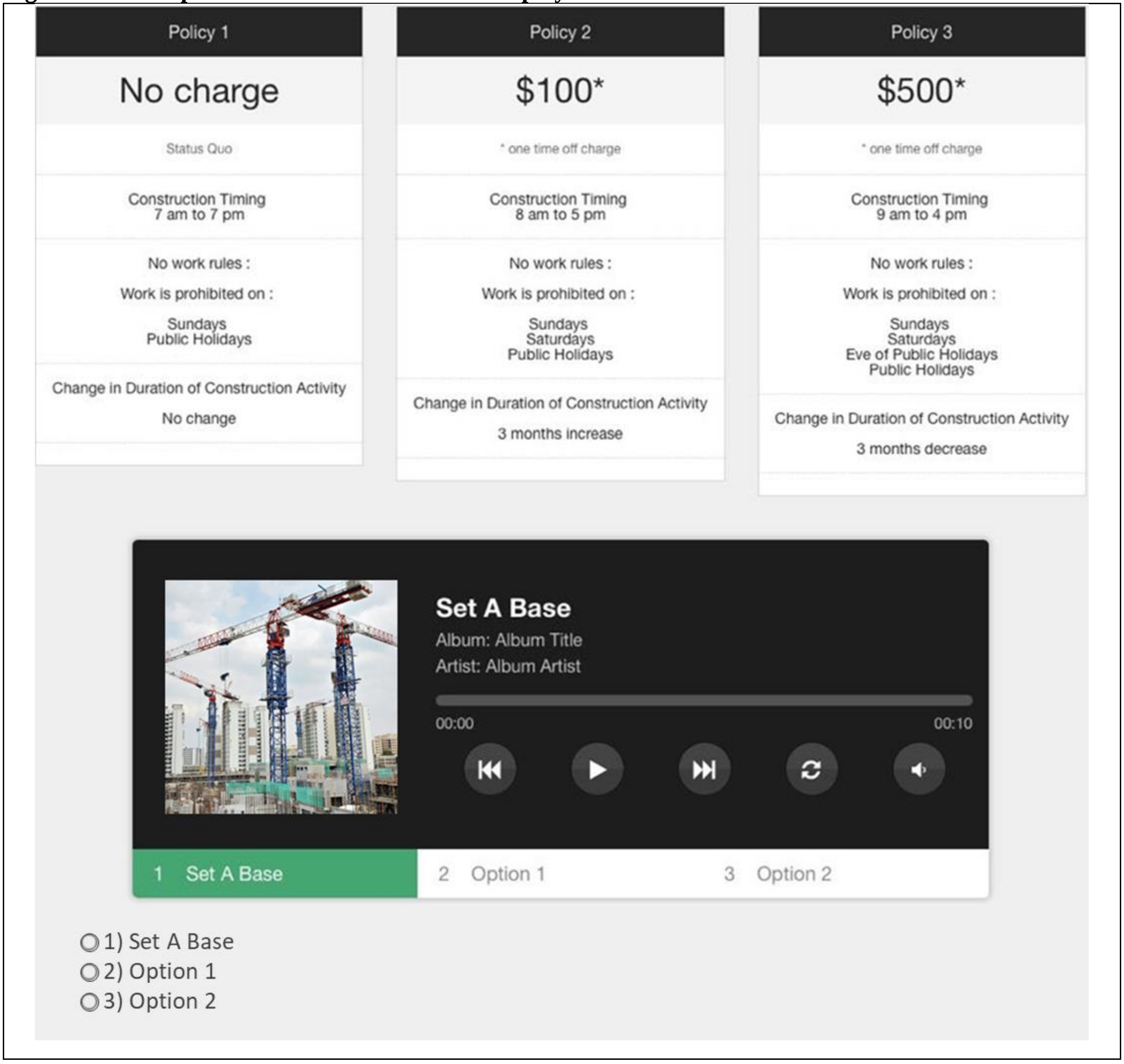
The generation of the efficient design required *a priori* knowledge of the values of the parameters, β. The survey questionnaires completed by respondents in the focus groups provided information on these priors. Further, the priors were updated as information from later phases of the survey became available. For instance, the design of the field survey questionnaire was informed by the priors obtained from the pilot field survey, which were in turn estimated based on the results of the laboratory survey.

6.4.5 Choice set design

Participants provided their views on different designs of the choice set layouts. Given that the audio-based questionnaires were novel, the focus group discussions focused on the design of these questionnaires. As discussed in Section 5.7, the choice sets used in the audio-based survey questionnaire depart from previous choice modelling surveys as the choice set incorporates audio and textual descriptions. As a result of the novel choice sets layout, it was necessary to code the choice set in hypertext mark-up language (HTML) and JavaScript. In the focus group discussions, the survey questionnaire was presented to respondents electronically, using similar equipment to that used in all phases of the survey. Each participant completed the survey on a Samsung Galaxy Tab 5 and Audio Technica M40x headphones.

In order to simplify the coding, the initial design of the choice set used a pre-coded audio player. This design is shown in Figure 6-3. Participants in the first two construction noise focus group discussions were presented with this choice set layout. Although most participants indicated that they understood the choice set layout, participants also said that it was troublesome to scroll down to make their choices. Some participants also commented that they had to match the sound clip associated with each policy when making their choice, which required effort since participants had to complete eight choice sets. As a pre-coded audio player was used in this choice set design, participants were able to continue to the next choice set without listening to all the sound clips. Consequently, some participants were able to make their choices without listening to the recordings.

Figure 6-3 Example of a choice set with an audio player

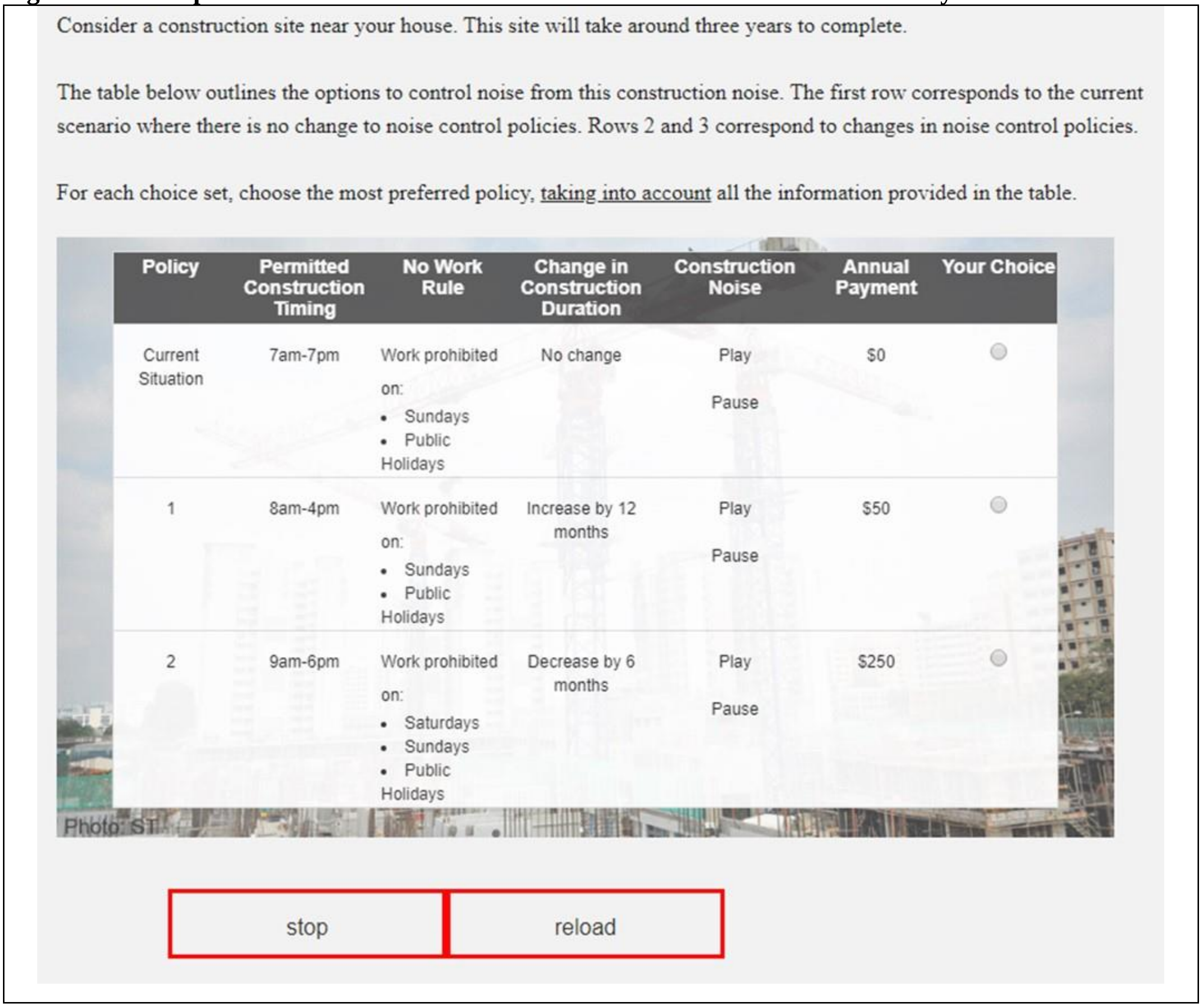


Given the shortcomings associated with the initial design of the choice set layout, the audio recordings were embedded into the choice set. The layout of this choice set for the construction and road noise survey questionnaires are shown in Figure 6-4 and Figure 6-5 respectively.[56] Participants in the third and fourth construction noise focus group discussions, as well as both the road noise discussions, were presented with the revised choice set. As

[56] A sample of the choice set prepared for the construction noise survey can be found at: https://chi-hoong.github.io/tryfile.

discussed in Section 5.7, this revised choice set was coded by the author and allowed for increased flexibility in the design of the choice set.

Figure 6-4 Example of choice set with embedded audio for construction noise survey



Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Your Choice
Current Situation	7am-7pm	Work prohibited on: • Sundays • Public Holidays	No change	Play Pause	$0	
1	8am-4pm	Work prohibited on: • Sundays • Public Holidays	Increase by 12 months	Play Pause	$50	
2	9am-6pm	Work prohibited on: • Saturdays • Sundays • Public Holidays	Decrease by 6 months	Play Pause	$250	

Photo: ST

stop reload

Figure 6-5 Example of choice set with embedded audio for road noise survey

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation Measures	Road Noise	Annual Payment	Your Choice
Current Situation	No additional policy is implemented	Play Pause	$0	○
1	Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.	Play Pause	$100	○
2	Construct roads with low-noise pavement material.	Play Pause	$300	○

stop reload

Participants said that the revised choice sets were easier to understand as compared to the choice set designed with a stand-alone player. As the audio clips were embedded directly into the table containing detailing the levels of each attribute, respondents did not have to scroll down to hear the noise recording associated with each option.

The design of this choice set required participants to listen to the sound clips associated with each option before participants are about to submit their response to the choice set. Participants were able to replay any sound clip when making their choices. As such, all sound clips were presented to participants and participants were able to review the sound clips before making a choice.

A stop button was also provided in the choice set. The stop button enables participants to stop all sounds playing should they have any concerns about the sounds in the choice set.

The stop button was provided to safeguard the well-being of the respondents. None of the participants in the focus group discussion used this button, possibly because the loudness of the sound clips was similar or quieter than the construction and road noise experienced at the homes of participants.

6.5 Demography questions and hearing acuity test

Participants' views on the demography questions and the hearing acuity test were also sought. Participants agreed that the demography questions were similar to other surveys and were not too intrusive. As such, no changes were made to the demography questions.

In contrast to the demography questions, the design of the hearing acuity test is novel. The hearing acuity test was designed to play a series of test tones to participants. Two tests were carried out, namely the descending test and the ascending test. In the descending test, a series of test tones with decreasing loudness was presented and participants were asked to click on the screen when they cannot hear a sound. For the ascending test, a series of test tones with increasing loudness was presented and participants were asked to click on the screen when they can just perceive a sound. While participants said that they understood the instructions, the first group of focus group participants found that there was a lag in the loading of the test tones. Specifically, during the descending test, some respondents thought that they could not hear a sound when, in actuality, the sound clip has not loaded. Consequently, some participants mis-clicked during the test.

Checks by the survey company indicated that the lag in the sound clip was due to a lack of bandwidth in their servers. In order to rectify the issues in the hearing acuity test, the test tones were compressed to smaller file sizes in the .mp3 format. Further, the survey company used a higher bandwidth server for subsequent surveys. Finally, the survey company attempted to load the survey questionnaire on the survey tablets ahead of the survey in order to cache the sound clips onto the tablets. As a result of these changes, loading speed was improved in later discussion groups, and respondents did not report a lag in the sound clips.

6.6 Overall survey design

Participants in the focus group discussions were also asked whether they had comments about the overall design and length of the survey questionnaire. Given that participants were presented with a series of potentially annoying construction or road noise, an overly lengthy survey may lead to survey fatigue. Participants indicated that the duration of the survey was acceptable. When asked to rank on a five-point Likert scale, with one corresponding to ‘strongly disagree’ and five corresponding to ‘strongly agree’, on average participants rated the survey at 4.7.

To conclude the focus group discussions, participants were asked about their overall understanding of the survey questionnaires. Participants said that the survey was easy to understand and that they understood the tasks they needed to complete in the survey. As such, the survey questionnaire was judged to be readily understandable to survey respondents.

6.7 Conclusion

The steps taken to refine the draft survey questionnaire presented in Chapter 5 were discussed in this chapter. A series of focus group discussions were conducted to understand the disamenities from construction and road noise pollution, the defensive measures residents have taken to mitigate these disamenities, and to review the draft survey questionnaire. In total, six focus groups discussions were conducted, four for construction noise and the remainder for road noise.

Results from the focus group discussions indicated that the main disamenity from living near construction sites and roads was noise pollution, justifying the motivation to examine the welfare changes arising from policies to mitigate construction and road noise. Participants were also asked about the annoyance arising from noise pollution, and their responses corroborate the findings from the acoustic engineering and audiology literature presented in Section 2.5.

Participants’ views on the policy context, the attributes and their levels, the payment vehicles, and layout of the choice set were sought. Participants agreed that the policy context was understandable and reflected Singapore’s context accurately. When presented with the candidate list of attributes and levels introduced in Section 5.6, participants agreed that the non-cost attributes corresponded with factors that affected them. Participants proposed a wide range of payment vehicles, most of which were not incentive compatible. Among the candidate payment vehicles presented Section 5.5, participants indicated that their preferred payment vehicle was a mandatory contribution to a community fund. The range of the cost attribute was also updated based on participants feedback. Participants indicated that the choice set layout which embedded noise recordings into the options was more understandable than a layout with a pre-coded audio player. Hence, the former layout was used in the finalised survey design.

Overall, participants found the survey questionnaire understandable and the length of the survey was acceptable.

The amended questionnaires are used to answer the research questions presented in Chapter 3. These surveys were carried out next. The next part of the thesis (comprising Chapters 7 to 11) presents the results from the surveys. The next chapter provides a description of the survey protocol as well as a summary of the socio-demographic characteristics of survey respondents. These characteristics were compared with Singapore’s demography to ascertain the representativeness of the sampling frame.

Chapter 7: Sample Statistics

This chapter begins the third part of the thesis (comprising Chapters 7 to 11), which discusses the findings from the survey designed in Chapters 4 to 6. To address the research questions presented in Chapter 3, two surveys were conducted to estimate the willingness-to-pay for construction road noise abatement. Each survey was carried out in phases. For the construction noise survey, a laboratory survey was conducted before the field survey. Each of these surveys comprised of pilot surveys followed by the main survey. The main field survey included a sub-sample that was presented with the text-based survey questionnaire. For the road noise survey, a field survey comprising of pilot surveys and a main survey was conducted.

In this chapter, the sample characteristics of survey respondents are presented. The sample characteristics provide information on the representativeness of the sampling frame. Sections 7.1 and 7.2 discuss the sample characteristics of the construction and road noise surveys respectively. Summary statistics on respondents' demographic profile is presented and compared to Singapore's demography. The annoyance caused by construction and road noise is also reported and discussed. In order for a stated preference survey to elicit respondents' true preferences, respondents need to agree with the scenarios presented in the survey questionnaire and must believe that the results of the survey will affect policy decisions on future noise abatement policy. Hence, Section 7.3 discusses the profile of respondents who returned anomalous responses.

As discussed in Chapter 4, these surveys were funded by the Ministry of the Environment and Water Resources and the Land Transport Authority. Media Research Consultants (MRC) was commissioned to administer these surveys. MRC is a subsidiary of MediaCorp, Singapore's largest media conglomerate, which has previously completed surveys for government agencies as well as private companies. A total of 2,012 respondents were surveyed across all phases of the surveys.

7.1 Construction noise survey

The construction noise survey was carried out over two phases. In the first phase, the survey was carried out in a laboratory environment. A pilot laboratory survey was first carried out, followed by the main laboratory survey. The sampling frame for the laboratory-based survey was drawn from MRC's panel of survey respondents. Respondents were invited to take part in the survey and respondent who agreed to participate travelled to a venue on MRC's premises to complete the survey.

The laboratory survey was carried out in order to control the background level of noise when respondents were completing the survey. Specifically, all respondents were exposed to low levels of background noise when completing the survey in the laboratory environment. By comparison, in a field survey, background noise levels may vary between respondents, depending on the location of the survey venue and the time-of-day when the survey was carried out. Further, the laboratory survey afforded the ability to troubleshoot any problems with the survey questionnaire. Given the novel design of the survey questionnaire, technical issues related to survey implementation could be more readily resolved in a laboratory setting as compared to a field setting.

The laboratory survey was carried out in two phases. A pilot survey of 40 respondents was conducted in February 2018. Responses of the pilot survey were analysed and the results of this survey were used as priors for an efficient design of the choice sets used in the main survey. The main survey comprised of 161 respondents and was conducted between February and April 2018. The survey was conducted in sessions, each of which had around 10 respondents completing the survey with the guidance of two surveyors.

Following the laboratory survey, field surveys were conducted. Two pilot surveys were first conducted. As discussed in Section 6.4.2, the pilot surveys sought to understand the difference in the willingness-to-pay when respondents were presented with a one-off or annual contributions to a community fund. The sample sizes for the first and second pilot surveys were 103 and 100 respectively. The main field surveys were then carried out. The field survey comprised of two sub-samples. First, 800 respondents were given a survey questionnaire that described changes to noise levels with noise recordings. Second, 203 respondents were presented with a textual description of changes in noise levels. This section describes the socio-demographic characteristics of each of these survey samples, followed by a discussion on the experience of living near construction sites.

The sampling frame for the field survey was obtained from Singapore's Department of Statistics.[57] The statistics department used a two-stage cluster design to select the sampling frame. In the first stage, the sampling frame was apportioned by planning areas based on the observed average demographic characteristics of each planning area.[58] The demographic characteristics of the planning area were obtained from Singapore's 2010 Census.[59] Next, specific households within each planning area were chosen at random. This sampling methodology sought to obtain a sampling frame that is broadly representative of Singapore's population and obtain a sample that represents both individuals living near and away from noise sources. Ideally, both laboratory and field surveys should draw respondents from the Department of Statistics' sampling frame. However, the laboratory survey requires respondents to travel to MRC's premises to complete the survey and respondents who are on MRC's panel of survey respondents are more likely agree to participate as they have self-selected their preference for participation by registering on the panel. By comparison, recruiting respondents from the Department of Statistics' sampling frame will likely result in high rejection rates, requiring the survey company to contact a large number of individuals.

When conducting the field survey, MRC's surveyors first approached households in the sampling frame. If this household refused or was unavailable to participate in the survey, the surveyor proceeded to a neighbouring household to conduct the survey. Two other replacement protocols were considered. First, the survey company could be required to visit unavailable households repeatedly until household declined to be interviewed. Second, additional sample households could be obtained from the Department of Statistics and households that declined to be surveyed would be replaced by the additional sample. However, both of these protocols were found to incur greater costs and required more time to complete the survey questionnaires

[57] The Department of Statistics provides a sample design and selection service for household survey. Services provided include consultation on sample design, selection of sample, and provision of a list of addresses for the survey. Details of this service can be found at: https://www.singstat.gov.sg/our-services-and-tools/sampling-service-for-household-surveys (Statistics Singapore 2019).

[58] The planning areas are demarcated by Singapore's Urban Redevelopment Authority (URA). The demographics of each planning area can be viewed at: https://www.ura.gov.sg/maps/ (URA 2019).

[59] Singapore's Census is conducted once every ten years. A total of 200,000 households were surveyed in 2010, representing around a fifth of Singapore's households (Statistics Singapore 2011).

as compared to the protocol used for the survey. Consequently, given budget and time constraints replacement of non-respondents with neighbouring households was used.

The first field survey presented respondents with a similar questionnaire as that used in the laboratory survey. The payment vehicle used in this questionnaire was a one-off contribution to a community fund. This pilot comprised of 103 respondents and was conducted between July 2018 and August 2018. Following the first pilot survey, a second pilot survey was conducted. The payment vehicle in the second pilot was an annual contribution to a community fund. A hundred respondents were surveyed in September 2018 in this pilot.

After the data from the pilot surveys were collected and analysed, the main field survey was conducted. A total of 800 respondents were surveyed between November 2018 and January 2019. Further, another 200 respondents were presented with a survey questionnaire which described changes to noise levels textually. Comparisons of the results to the textual questionnaire and the questionnaire that described noise with audio recordings provide insight into how different descriptions of noise lead to different stated preferences for noise abatement. These 200 respondents to the textual survey were surveyed in January 2019.[60]

7.1.1 Demographic distribution

In order to ensure that the survey sample is representative of Singapore's resident population, demographic details of respondents were compared with the aggregate statistics for Singapore's population. The statistics for Singapore's population were obtained from the Department of Statistics (Statistics Singapore 2018c, 2018a).

7.1.1.1 Laboratory survey

The socio-demographic characteristics of laboratory survey respondents are presented in Table 7-1. Overall, the profile of the respondents is representative of Singapore's population. In the main survey, there were no statistical differences between the sample and the population for age, gender distribution, ethnicity distribution, and housing type.

[60] The surveys for the audio-based main survey and text-based surveys were staggered by the survey company as there were insufficient surveyors to complete both surveys concurrently. A possible shortcoming of staggering the survey was that some respondents to the audio-based main survey were surveyed over the Christmas and New Year. In total, 30 respondents were survey on the eves and actual dates of Christmas and New Year. This represented less than 5% of the total sample. Results of analysis presented in later chapters were robust to the exclusion of these respondents.

Table 7-1 Summary statistics of respondents in the construction noise laboratory survey

	Population	**Pilot survey**	**Main survey**
Number of respondents (number)	-	40	161
Median age (years)	41	39.5^{**} (0.05)	40 (0.60)
Median monthly household income (S$)	7900	7001 (0.67)	6634^{***} (0.00)
Gender distribution (%)			
Male	51	38^{*} (0.08)	52 (0.77)
Female	49	63^{*} (0.08)	47 (0.65)
Prefer not to state	-	0 (-)	0.6 (-)
Ethnicity distribution (%)			
Chinese	74	80 (0.39)	75 (0.74)
Malay	13	7.5 (0.30)	12 (0.65)
Indian	9.0	10 (0.83)	10 (0.67)
Others	3.2	0 (-)	1.2 (0.16)
Prefer not to state	-	2.5 (-)	1.9 (-)
Dwelling type (%)			
Public housing	79	83 (0.59)	77 (0.53)
Private property	21	15 (0.35)	19 (0.59)
Prefer not to state	-	2.5 (-)	3.7 (-)
Highest level of education (%)			
Up to secondary	44	10^{***} (0.00)	26^{***} (0.00)
Post-secondary	24	20 (0.55)	32^{**} (0.023)
Degree or above	31	65^{***} (0.00)	39^{**} (0.026)
Prefer not to state	-	2 (-)	3.1 (-)

* $p<0.1$, ** $p<0.05$, *** $p<0.01$, *p*-values are shown in brackets.
Note: Medians were tested with the Wilcoxon signed-ranks test. Averages were tested with t-tests. Percentages were tested with proportion tests. If *p*-value of a statistic was omitted, no corresponding population statistic was available. Population statistics were obtained from Singapore's Department of Statistics (Statistics Singapore 2018c, 2018a).

However, the median household income of the sample was significantly different from the population median. The difference may be due to selection bias, as higher income individuals might be more unwilling to participate in the laboratory survey due to the higher opportunity costs if an individual earns a higher income. Respondents might also have systematically understated their income. Other studies have found that self-reported income may have a downward bias as respondents may not know their wages accurately or may have deliberately misreported their incomes (Atkinson & Micklewright 1983; Thatcher 1968).

Nonetheless, there is insufficient evidence to determine whether such misreporting occurred in the survey.[61]

The sampling frame also over-represented individuals with university education and under-represented secondary and below educated individuals. The discrepancy may be due to the difficulty with achieving a sampling frame that is statistically similar to the population given that the total number of respondents was only 201.

7.1.1.2 Field survey

Summary statistics of the socio-demographic characteristics of the field survey for construction noise are presented in Table 7-2. Similar to the laboratory survey, several demographic characteristics in the sample were statistically different from the population.

[61] The data on the median household income in Singapore was obtained from the Department of Statistics. The data was collected under the auspices of the Statistics Act, which imposes penalties for falsification of information (Singapore Statutes 2012). However, the data collected in this survey was not collected under the Statistics Act, and there were no penalties associated with providing incorrection information. Consequently, misreporting is more unlikely to occur in the population data as compared to the survey data.

Table 7-2 Summary statistics of respondents in the construction noise field survey

	Population	Audio-based survey			Text-based survey
		Pilot survey 1	Pilot survey 1	Main survey	
Number of respondents (number)	-	103	100	800	203
Median age (years)	41	47*** (0.00)	42** (0.03)	47*** (0.00)	42*** (0.01)
Median monthly wage (S$)	3467	2513*** (0.00)	2912*** (0.00)	2484*** (0.00)	3339**** (0.01)
Gender distribution (%)					
Male	51	47 (0.49)	45 (0.23)	47** (0.04)	55 (0.23)
Female	49	52 (0.49)	54 (0.32)	53** (0.04)	45 (0.23)
Prefer not to state	-	0 (-)	1 (-)	0 (-)	0 (-)
Ethnicity distribution (%)					
Chinese	74	65** (0.04)	65** (0.04)	74 (0.94)	80** (0.04)
Malay	13	16 (0.44)	19* (0.07)	13 (0.83)	10 (0.26)
Indian	9.0	14 (0.10)	11 (0.48)	10 (0.46)	5.9 (0.12)
Others	3.2	1.9 (0.13)	1.0 (0.64)	2.5 (0.90)	2.4 (0.55)
Prefer not to state	-	3.9 (-)	3.0 (-)	0.25 (-)	1.0 (-)
Dwelling type (%)					
Public housing	79	92*** (0.00)	97** (0.00)	85*** (0.00)	73* (0.05)
Private property	21	7.8*** (0.00)	2*** (0.00)	15*** (0.00)	26* (0.07)
Prefer not to state	-	0 (-)	1.0 (-)	0 (-)	0.5 (-)
Highest level of education (%)					
Up to secondary	44	50 (0.25)	41 (0.55)	45 (0.67)	32*** (0.00)
Post-secondary	24	35*** (0.01)	26 (0.64)	25 (0.50)	32** (0.01)
Degree or above	31	16*** (0.00)	28 (0.51)	29 (0.16)	34 (0.22)
Prefer not to state	-	0 (-)	2 (-)	2 (-)	2 (-)

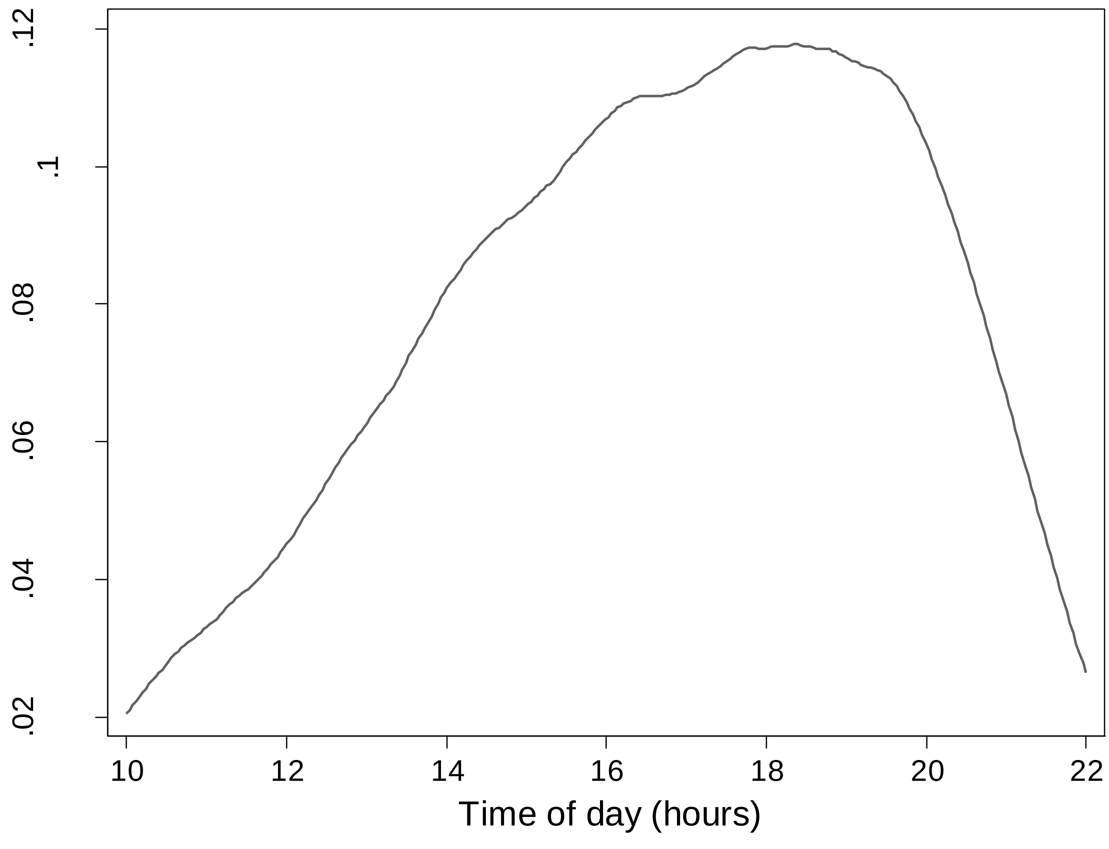
* p<0.1, ** p<0.05, *** p<0.01, *p*-values are shown in brackets.
Note: Medians were tested with the Wilcoxon signed-ranks test. Averages were tested with t-tests. Percentages were tested with proportion tests. If *p*-value of a statistic was omitted, no corresponding population statistic was available. With the exception of individual incomes, population statistics were obtained from Singapore's Department of Statistics (2018b, 2018a). Individual incomes were obtained from Singapore's Ministry of Manpower (2019).

Across all phases of the survey, the median age of respondents was higher in the sample as compared to the population, indicating that older respondents were over-represented in the survey sample. Further, the median self-reported wage of respondents was also lower as compared to the population median. Unlike the laboratory survey, which asked individuals about their household income, the field surveys asked about the wage of the individual. This revision was carried out in order to align the income of the individual with the sampling frame provided by the Department of Statistics.

Across all phases of the field survey, the proportion of females surveyed was higher as compared to the population. With the exception of the main audio-based field survey, the gender distributions in the survey sample were not statistically different from the population. The statistical significance in the main survey may have been due to the large sample size of this survey as compared to other survey phases, leading to lower standard errors.

A possible reason for the oversampling of older, lower income, and female respondents may be the time-of-day and day-of-week when surveys were conducted. In total, around a third of surveys were conducted over weekends, when working adults were more likely to be home. Among the remaining surveys conducted on weekdays, more than three-quarters of surveys were conducted before 6pm (Figure 7-1). Another reason for the lower reported income levels in the survey may be due to a systematic downward bias in self-reported income.

Figure 7-1 Time-of-day that construction noise surveys were conducted



Note: Only surveys conducted on weekdays were included in the density plot.

The survey included all main ethnicities in Singapore. In the pilot surveys, Chinese respondents were under-represented while Chinese were over-represented in the text-based survey. In the main field survey, the proportion of each ethnicity in the sampling frame was similar to the population.

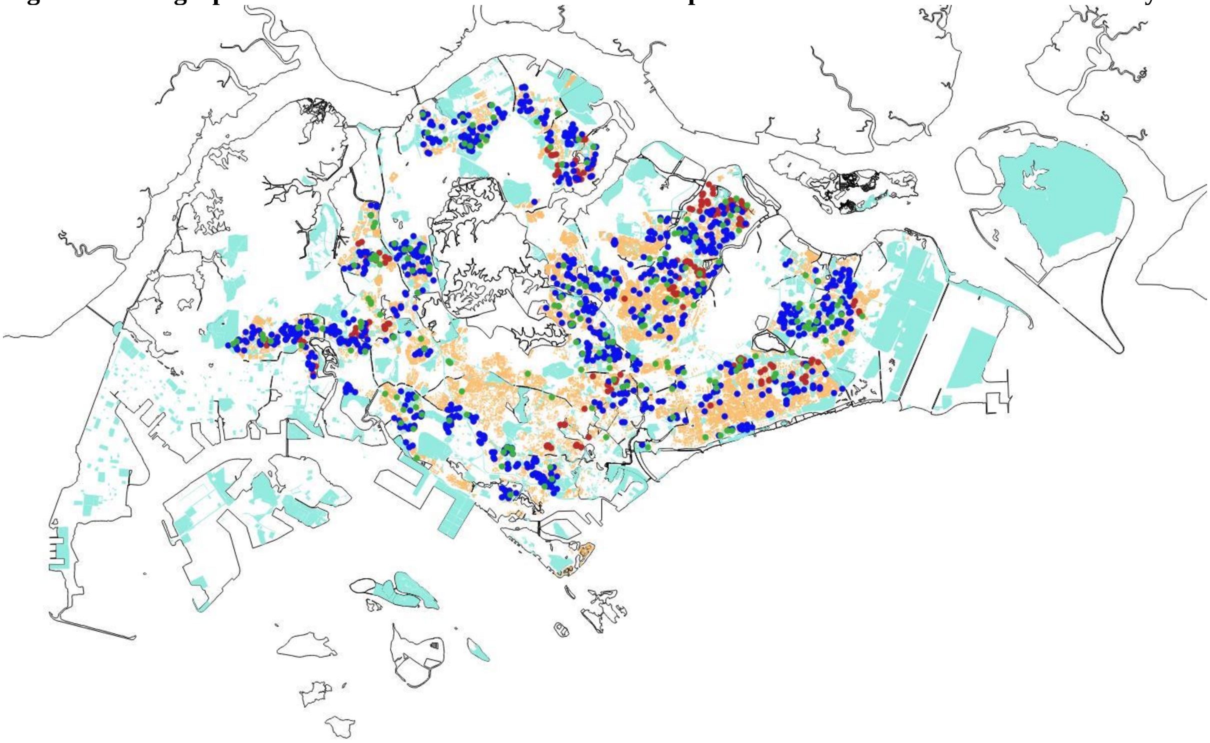
Respondents to the survey lived in both public and private housing. Public housing was defined to be residences constructed by the Housing Development Board (HDB). The remainder of the population lived in private property, including, condominiums, apartments, and landed property. In the two pilot surveys, respondents living in public housing were oversampled. However, the survey company increased the proportion of respondents from private housing in the main field survey and text-based survey. The survey company indicated that it was necessary to obtain approval from the management committee at condominiums before surveyors were able to enter the development. Consequently, the survey company obtained more respondents living in private properties for the main audio-based and text-based surveys, which were carried out over a longer time period as compared to the pilot surveys.

Respondents' education attainments ranged from secondary and below to university education. In the text-based survey, education attainment was statistically different from the population. Respondents with secondary and below education were under-represented while respondents with up to post-secondary were over-represented.

7.1.2 Annoyance with construction noise

In terms of geographical distribution, respondents to the construction noise survey were drawn from across the whole of Singapore. As depicted in Figure 7-2, respondents were drawn from all major planning districts in Singapore.

Figure 7-2 Geographical distribution of the residences of respondents to the construction noise survey

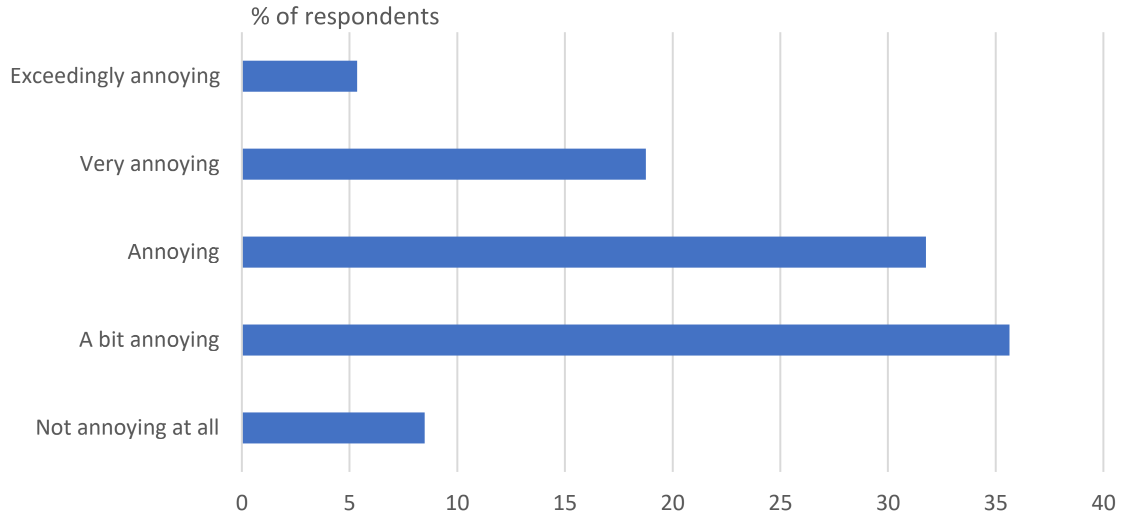


Note: Light blue areas refer to construction sites which have obtained a permit to commence work and have not obtained a completion permit, i.e., construction activity is ongoing at these sites. Orange areas denote residences in Singapore. Green markers refer to residences of respondents to the laboratory survey, blue markers refer to respondents to the field survey with recorded construction noise and red markers refer to respondents to the field survey with textual description. Location of construction sites and

Among all respondents in the construction noise surveys, 858 respondents (60% of all respondents) reported that they have lived near a construction site. Among all respondents, the median distance between residences and construction sites was 62 metres, which is not statistically different from the population median of 76 metres at the 10% level of significance.

A majority (91.5%) of respondents who lived near construction sites indicated that they were annoyed by the construction activity on some level (Figure 7-3). Only 8.5% of respondents reported that they were not annoyed by construction noise. By comparison, 56% of respondents said that they found construction noise annoying. These results were expected given Singapore's high density of construction activity in close proximity with residences.

Figure 7-3 Annoyance due to construction noise



7.2 Road noise survey

The surveys to estimate the willingness-to-pay for road noise abatement were all conducted in the field. Similar to the field survey for construction noise, the sampling frame for the surveys was designed by Singapore's Department of Statistics, using the same sampling methodology. The survey company also used the same respondent replacement protocol as the construction noise survey when conducting the survey.

The road noise survey was conducted in three phases. In the first phase, a pilot survey was conducted with 53 respondents between July 2018 and August 2018. In this pilot survey, the payment vehicle presented to respondents was a one-off contribution to a community fund. Next, the survey questionnaire was revised to use an annual construction to a community fund instead. The revised questionnaire was presented to respondents in the second pilot survey, which comprised of 52 respondents and was conducted between September 2018 and October 2018. After the pilot surveys were concluded and the data was analysed, the main field survey was conducted. 500 respondents were surveyed between November 2018 and January 2019.

7.2.1 Demographic distribution

The summary statistics of the road noise surveys are presented in Figure 7-5. Similar to the construction noise surveys, several demographic characteristics in the sample were statistically different from the population.

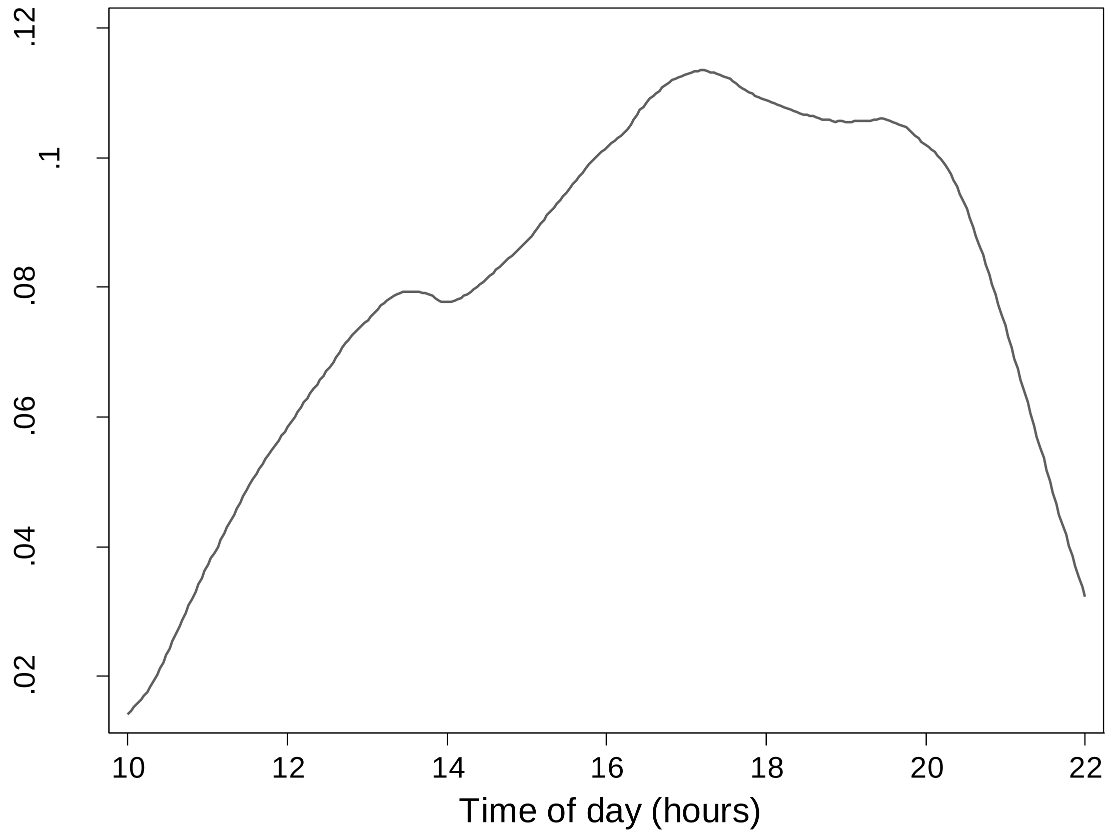
Table 7-3 Summary statistics of respondents in the road noise survey sample

	Population	**Pilot survey 1**	**Pilot survey 1**	**Main survey**
Number of respondents (number)	-	53	52	500
Median age (years)	41	47^{***} (0.00)	42 (0.24)	47^{***} (0.00)
Median monthly wage (S$)	3467	3200^{***} (0.00)	2500^{***} (0.00)	2500^{***} (0.00)
Gender distribution (%)				
Male	51	51 (0.99)	44 (0.33)	50 (0.53)
Female	49	49 (0.99)	51 (0.67)	50 (0.53)
Prefer not to state	-	0 (-)	4 (-)	0 (-)
Ethnicity distribution (%)				
Chinese	74	64 (0.10)	65 (0.16)	80^{***} (0.00)
Malay	13	15 (0.65)	19 (0.18)	11 (0.14)
Indian	9.0	9.4 (0.91)	9.6 (0.88)	7.4 (0.21)
Others	3.2	11^{***} (0.00)	3.9 (0.79)	1.8^{*} (0.08)
Prefer not to state	-	0 (-)	1.9 (-)	0.2 (-)
Dwelling type (%)				
Public housing	79	96^{***} (0.00)	94^{***} (0.00)	76 (0.15)
Private property	21	3.7^{***} (0.00)	3.9^{***} (0.00)	24 (0.15)
Prefer not to state	-	2.5 (-)	2.5 (-)	2.5 (-)
Highest level of education (%)				
Up to secondary	44	43 (0.93)	38 (0.42)	40^{*} (0.06)
Post-secondary	24	32 (0.17)	34^{*} (0.07)	28^{*} (0.06)
Degree or above	31	23 (0.18)	31 (0.35)	31 (0.92)
Prefer not to state	-	0 (-)	2 (-)	2 (-)

* $p<0.1$, ** $p<0.05$, *** $p<0.01$, *p*-values are shown in brackets.
Note: Medians were tested with the Wilcoxon signed-ranks test. Averages were tested with t-tests. Percentages were tested with proportion tests. If *p*-value of a statistic was omitted, no corresponding population statistic was available. With the exception of individual incomes, population statistics were obtained from Singapore's Department of Statistics (2018b, 2018a). Individual incomes were obtained from Singapore's Ministry of Manpower (2019).

Respondents to the road noise survey were older and earned lower incomes as compared to the population. These differences are statistically significant for the main survey. Sampling methodologies may have contributed to the oversampling of older and lower income respondents. Similar to the construction noise field surveys, around a third of responses were collected over weekends. Among surveys conducted on weekdays, 72% were conducted during working hours before 6pm. (Figure 7-4). Respondents may also have under-reported their incomes.

Figure 7-4 Time-of-day road noise surveys were conducted



Note: Only surveys conducted on weekdays were included in the density plot.

Across all phases of the road noise survey, the proportions of males and females were not statistically different from the population. While the proportion of Chinese respondents were over-represented and statistically different from the population proportion in the main survey, the proportions of Malay and Indian respondents were not statistically different from the population. However, respondents with other ethnicities were under-represented and statistically different from the population at the 10% level of significance.

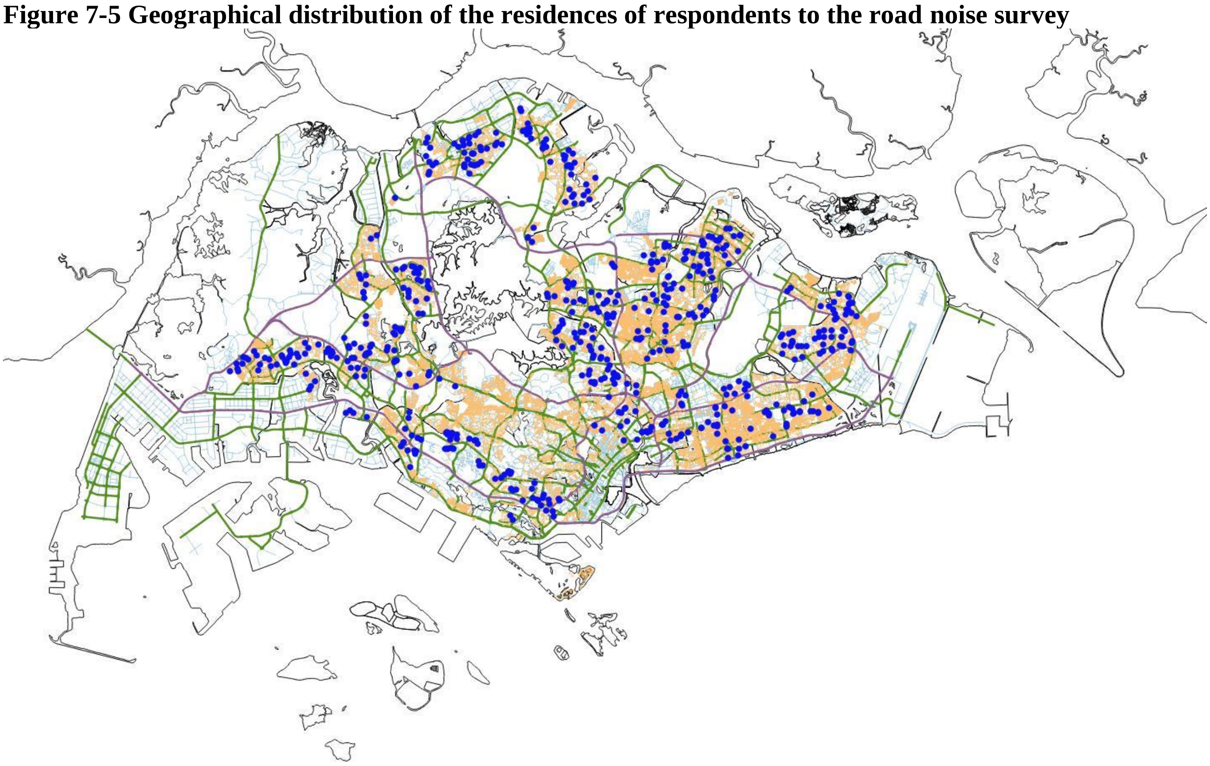
Respondents living in public housing were over-represented in the pilot surveys. As discussed in the previous section, this was due to difficulties with entering condominiums and apartments to conduct surveys given that the pilot surveys were completed over a short time period. By comparison, the main survey had a higher proportion of respondents living in private housing, such that the distribution was not statistically different from the population. Educational attainment of respondents was also distributed across all levels of education.

Specific to the main survey, individuals with secondary and below education were under-represented, while individuals with post-secondary education were over-represented.

7.2.2 Annoyance with road noise

Respondents to the road noise survey were drawn from across the whole of Singapore (Figure 7-5). 44% of respondents indicated that they lived near major roads, which include arterial roads and expressways. The median distance between respondents' residences and major roads was 181 metres. By comparison, the median distance between all residences and the nearest major road was 185 metres. The median distance between residences and major roads in the survey sample was not statistically different from the population median.

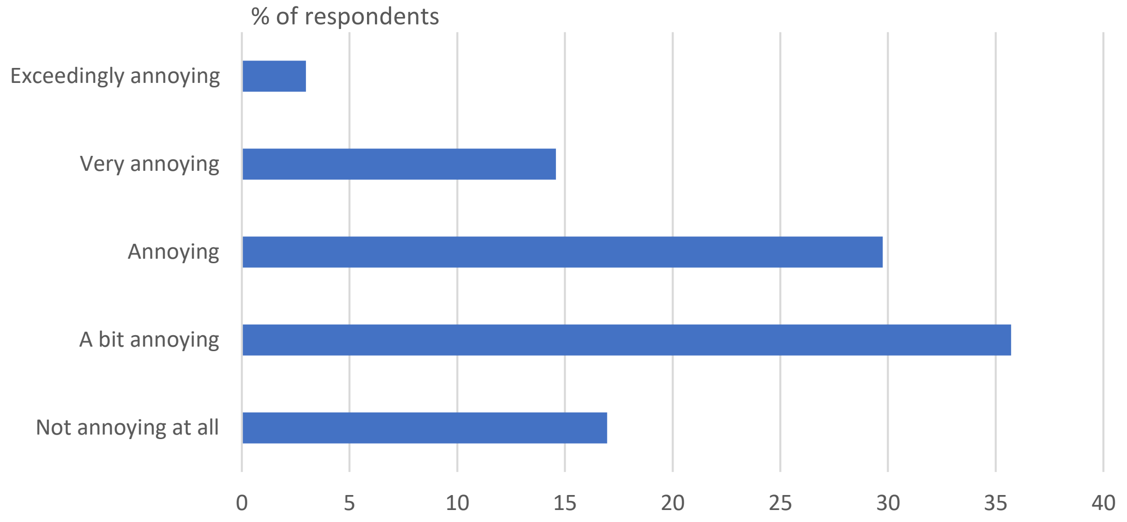
Figure 7-5 Geographical distribution of the residences of respondents to the road noise survey



Note: Purple, green and light blue lines denote expressways, arterial roads and minor roads respectively. Orange areas denote residences in Singapore. Blue markers refer to residences of respondents to the survey.

Among respondents who reported living near roads, a majority (83%) indicated that they were annoyed by road noise (Figure 7-6). Around 17% of respondents reported that they were not annoyed by road noise. However, a total of 48% of respondents were annoyed by the noise. These results were symptomatic of Singapore's dense road network and the number of residents living near the roads.

Figure 7-6 Annoyance due to road noise



7.3 Anomalous responses

A choice modelling survey could be subject to various types of behavioural anomalies (Johnston et al. 2017). In this section, two forms of anomalous responses were respondents who rejected the policy scenario in the survey questionnaire and respondents who thought that the survey questionnaire was inconsequential. As discussed in Section 5.9.4, questions were included in the survey questionnaires to ascertain the validity of responses. The incidences of anomalous responses are discussed in turn.

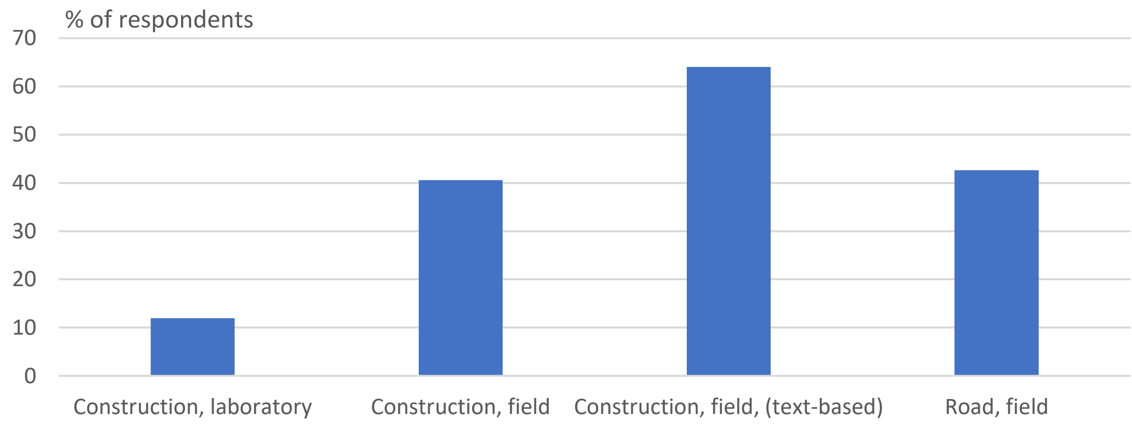
7.3.1 Protest responses

Respondents who reject the policy scenario are termed protest respondents. These respondents fulfil two criteria simultaneously. First, protest respondents universally chose the status quo option. Second, respondents who universally chose the status quo option cited that they supported the implementation of noise abatement, but (i) did not think that they should be paying for the noise abatement measures and/or (ii) did not think that their payment will be effectively used to reduce noise. Respondents who universally chose the status quo option may have done so due to mitigating factors, such as budgetary constraints or they may not be adversely affected by noise pollution (Jorgensen et al. 1999). These respondents were not classified as being protest respondents. By comparison, protest respondents do not interpret the scenarios as intended and instead reject the proposed policy changes (von Haefen, Massey & Adamowicz 2005). These protest respondents do not reveal their true preferences.

Figure 7-7 illustrates the proportion of respondents who universally chose the status quo option. The laboratory survey yielded the lowest proportion of these respondents, where 12% of respondents universally chose the status quo option. By comparison, 40% of respondents to the construction noise field survey chose only the status quo option. This proportion increased to 64% among respondents to the text-based survey. Among respondents to the road noise field survey, around 43% of respondents only chose the status quo. Selection bias may have caused the lower incidence of respondents who universally chose the status quo option in the laboratory survey as compared to the other survey phases.

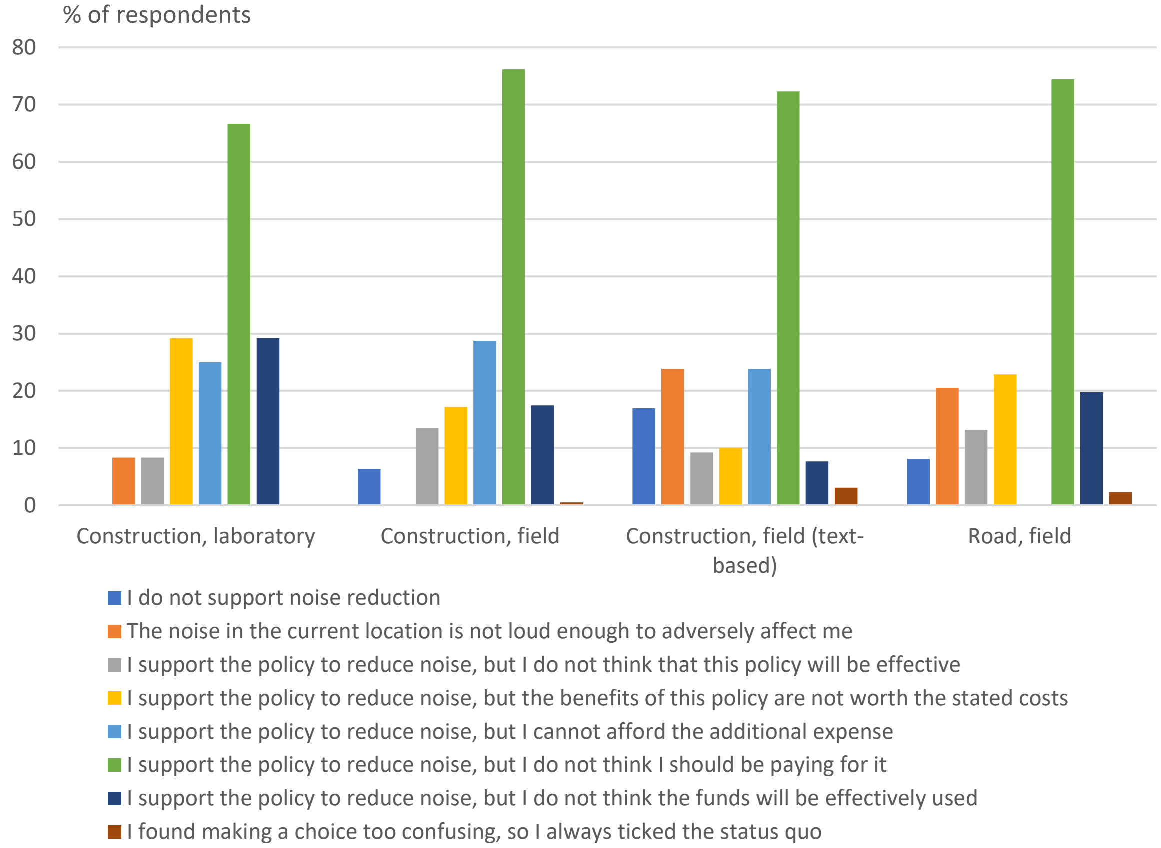
Respondents who agreed to participate in the laboratory survey had to invest time and effort to travel to the survey company's venue. Consequently, respondents to the laboratory survey may have been more willing to choose alternatives to the status quo since they have already invested in the time and effort to participate in the survey. Nonetheless, since the preferences of individuals who declined to participate in the laboratory survey are not observed, reasons for the difference in the proportion of respondents who universally chose the status quo option cannot be identified.

Figure 7-7 Proportion of respondents who universally chose the status quo option



As discussed in Section 5.9.4, debriefing questions after respondents completed the choice sets sought to understand the reasons that cause a respondent to choose only the status quo option. The reasons provided by respondents are shown in Figure 7-8.

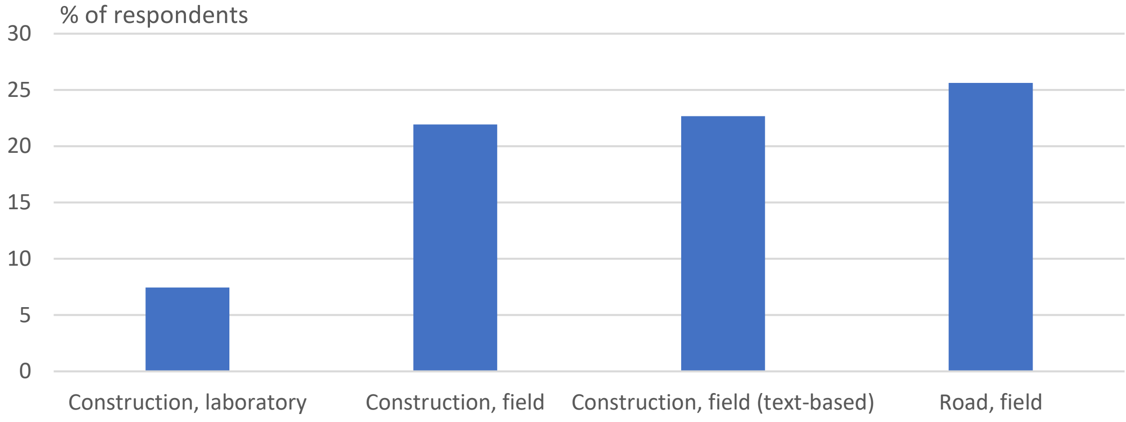
Figure 7-8 Reasons for respondents choosing only the status quo option



The main reason respondents cited for choosing only the status quo option was that they supported the policy to reduce noise, but they did not think that they should pay for noise abatement. Respondents also cited concerns regarding the effective use of funds to provide noise abatement as well as about the efficacy of noise abatement measures. By contrast, only a small minority of respondents said that they chose the status quo option for all choice scenarios as they could not understand the choices they were asked to make. Across all phases of the survey, only 1.5% of respondents cited this reason. Consequently, reasons cited by respondents who universally chose the status quo option suggest that they understood the choice scenarios and chose only the status quo option as they felt the costs of implementing this policy should be borne by other parties.

After accounting for the reasons that respondents universally chose the status quo option, protest respondents were identified. The proportion of protest respondents in each phase of the survey is shown in Figure 7-9. In the laboratory survey, 7% of respondents were protest respondents. In the main audio- and text-based construction surveys, the proportion of protest respondents was 22% and 23% respectively. Finally, in the road noise survey, the proportion of protest respondents was 26%.

Figure 7-9 Proportion of respondents who returned protest responses



In order to understand how demographic profiles affect the probability that an individual is a protest respondent, a logistic regression was estimated. The specification of the regression is as follows:

$$\Pr(protest = 1)_i = \Lambda(X_i\beta + \varepsilon_i) \qquad (7\text{–}1)$$

where $\Pr(protest = 1)_i$ represents the probability that individual i is a protest respondent. To estimate the regression, $\Pr(protest = 1)_i$ is a dummy variable taking a value of one if individual i is a protest respondent and zero otherwise. X_i is a vector of demographic characteristics associated with individual i. Demographic characteristics included in the regression include age, gender, ethnicity, income, dwelling type, household size, and education attainment. β is a vector of regression coefficients, ε_i is a random error associated with individual i, and $\Lambda(\cdot)$ denotes the logistic function.

Table 7-4 Effect of demographic profile on probability of a respondent returning a protest response

	(1)	(2)	(3)	(4)
	Construction noise			Road noise
	Laboratory	Field	Text-based	Field
Age	-0.00102	-0.000250	0.0187***	0.01000**
	(0.00890)	(0.00304)	(0.00664)	(0.00415)
Female	-0.469**	-0.00408	-0.0980	-0.0701
	(0.205)	(0.0877)	(0.196)	(0.111)
Ethnicity				
Malay	-0.472	-0.446***	0.633**	-0.208
	(0.362)	(0.140)	(0.322)	(0.182)
Indian	-0.348	-0.431***	-0.751*	-0.275
	(0.378)	(0.157)	(0.412)	(0.217)
Other		-0.218	0.841	-0.203
		(0.245)	(0.697)	(0.352)
Private housing	0.148	0.225*	-0.206	0.137
	(0.272)	(0.128)	(0.235)	(0.144)
Income	-0.00000413	-0.0000425**	0.0000468	-0.0000524*
	(0.0000299)	(0.0000209)	(0.0000360)	(0.0000279)
Household size	0.0830	-0.00162	-0.0917	-0.0137
	(0.0743)	(0.0150)	(0.0660)	(0.0382)
Education attainment				
Post-secondary	0.225	0.0387	0.209	0.182
	(0.300)	(0.118)	(0.268)	(0.147)
Bachelor's degree or higher	0.286	-0.00615	0.574**	0.0433
	(0.287)	(0.127)	(0.281)	(0.170)
Constant	-0.895	-0.435**	-1.305***	-0.836***
	(0.562)	(0.211)	(0.482)	(0.322)
pseudo R^2	0.054	0.022	0.091	0.027
AIC	228.0	1160.4	258.4	738.6
BIC	260.9	1214.4	294.9	787.0
Number of observations	199	1003	203	605

* p<0.1, ** p<0.5, *** p<0.01, robust standard errors are shown in brackets.
Note: Age, Income, and Household size were continuous variables representing respondent's age, income, and household size respectively. All other variables were dummy variables. Female was assigned a value of one if the respondent was female. The ethnicity variables, Malay, Indian, and Other, were assigned a value of one if a respondent was in that particular ethnicity. Other also took a value of one if the respondent did not state their ethnicity. The base ethnicity was Chinese. Other ethnicities were omitted in the construction noise laboratory survey as there was no within-group variation. Private housing took a value of one if the respondent lives in private housing. The base housing type was public housing. Post-secondary and Bachelor's degree or higher took a value of one if the respondents completed up to post-secondary education (i.e., Junior College or Polytechnic) and university education respectively. The baseline education level was Secondary.

Results of the logistic regression are shown in Table 7-4. In the text-based construction survey and the road noise survey, older respondents were more likely to be protest respondents. Females were less likely to be protest respondents in the laboratory construction noise survey. Ethnicity had a statistically significant effect in the main audio- and text-based construction noise surveys. In both surveys, Indians were less likely to be protest respondents. Malays were less likely to be protest respondents in the audio-based survey but were more likely to be protest respondents in the text-based survey. Increased income was associated with a lower probability of protest in the main audio-based construction survey and the road noise survey. Living in private housing was associated with an increased probability of protest. Household size had no statistically significant effect on the probability that a respondent will be a protest respondent. Education attainment was only statistically significant for the text-based construction noise survey. Respondents who attained university education were more likely to be protest respondents.

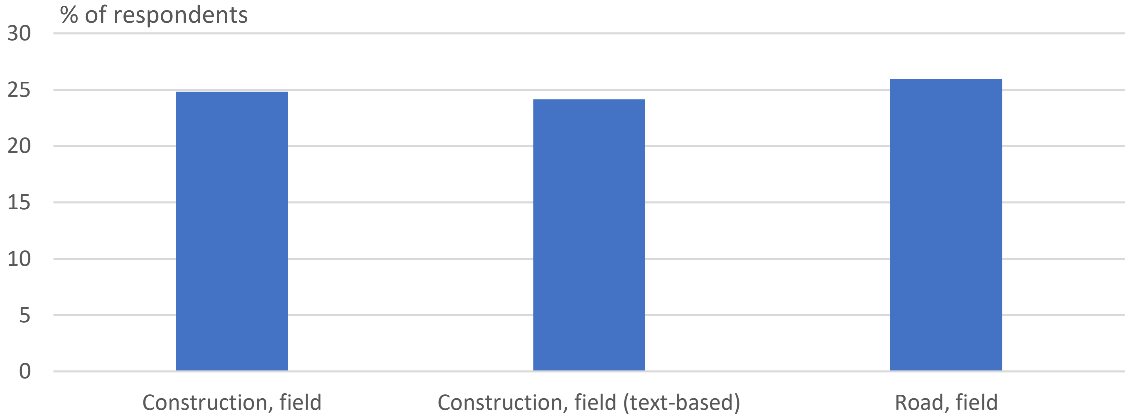
In order to ensure that regression estimates are not biased by protest respondents, researchers suggest exclusion of protest responses from the analysis (Edwards and Anderson, 1987; Milon, 1989). As such, the effect of protest respondents on the estimated average preferences from regression analysis are analysed in the following chapters.

7.3.2 Respondents who viewed the survey questionnaire as being inconsequential

The second behavioural anomaly arises from respondents who viewed the survey questionnaire as being inconsequential. These respondents indicated that their responses will not affect future policies related to noise abatement. As discussed in Section 5.2.2, respondents must believe that the survey is consequential in order for the survey to be incentive compatible.

The proportions of individuals who believed that the survey was inconsequential are depicted in Figure 7-10.[62] Across the audio- and text-based construction noise surveys and the road noise survey, around a quarter of respondents said that they did not believe that the survey will affect future noise abatement policies. These respondents may not reveal their true preferences when answering the survey questionnaire.

Figure 7-10 Proportion of respondents who thought the survey was inconsequential



A logistic regression was also estimated to understand the effects of demography on the probability that a respondent did not believe that the survey questionnaire was consequential. Results of the analysis are shown in Table 7-5.

[62] Due to a coding error in the laboratory survey questionnaire, the responses for respondents views on the consequentiality of the survey was not recorded.

Table 7-5 Effect of demographic profile on probability of a respondent thought that the survey was inconsequential

	(1)	(2)	(3)
	Construction noise		Road noise
	Field	Text-based	Field
Age	-0.000225	0.0155**	0.00323
	(0.00321)	(0.00698)	(0.00427)
Female	-0.0906	-0.130	0.122
	(0.0892)	(0.206)	(0.115)
Ethnicity			
Malay	-0.362**	0.196	-0.215
	(0.141)	(0.326)	(0.185)
Indian	-0.358**	-0.360	-0.491**
	(0.157)	(0.433)	(0.235)
Other	-0.229	-0.159	-0.0898
	(0.252)	(0.590)	(0.346)
Private housing	0.186	-0.232	0.0373
	(0.130)	(0.253)	(0.149)
Income	-0.0000127	-0.0000286	-0.0000456
	(0.0000215)	(0.0000406)	(0.0000280)
Household size	-0.0571*	0.00380	0.0572
	(0.0293)	(0.0625)	(0.0388)
Education attainment			
Post-secondary	-0.0289	0.531**	0.136
	(0.122)	(0.268)	(0.145)
Bachelor's degree or	-0.0110	0.268	-0.00768
higher	(0.127)	(0.299)	(0.168)
Constant	-0.435**	-1.305***	-0.836***
	(0.211)	(0.482)	(0.322)
pseudo R^2	0.020	0.045	0.020
AIC	1123.9	236.2	701.2
BIC	1178.0	272.6	749.7
Number of observations	1003	203	605

* p<0.1, ** p<0.5, *** p<0.01, robust standard errors are shown in brackets.
Note: See Table 7-4 for definitions of independent variables.

Older respondents in the text-based survey were more likely to not believe the consequentiality of the survey. Ethnicity had a statistically significant effect in the main audio-based construction survey and the road noise survey. Indians were more likely to believe that the survey was consequential in both of these surveys. In addition, Malays were more likely to believe in the consequentiality of the audio-based construction noise survey. Respondents in the audio-based construction survey were less likely to think that the survey was inconsequential. Across all surveys, gender, dwelling type and income had no effect on the likelihood that the respondents thought that the survey was inconsequential. With the exception of post-secondary respondents to the text-based construction survey, education attainment also had no effect on beliefs about survey consequentiality.

In order to ensure that the sample excluded anomalous responses, the effect of exclusion of respondents who viewed the survey as being inconsequential is estimated in the following chapters.

7.3.3 Correlation between protest respondents and respondents who viewed survey questionnaire as being inconsequential

Across all phases, around A 16% of respondents returned protest responses and viewed the survey questionnaire as being inconsequential. Further, a quarter of respondents were protest respondents but thought that the survey will affect policy, while 7% of respondents thought that the survey was inconsequential but were not protest respondents.

Broken down by phases, around 36% and 41% returned anomalous responses in the construction audio survey and text survey respectively. Further, in the road noise survey, around 40% of the respondents returned anomalous responses. These proportions are shown in Figure 7-11.

Figure 7-11 Breakdown of anomalous responses by survey phases

7.4 Conclusion

This chapter began the third part of the thesis by presenting the summary statistics of the various surveys conducted in this study. Based on the summary statistics, around 60% of the respondents to the construction noise survey indicated that they have experienced construction noise at their homes. Further, 40% of respondents to the road noise survey said that they experienced road noise at their homes. Among respondents who experienced construction or road noise at their homes, a majority reported that they were annoyed by noise due to construction activity or roads. These findings justify the research motivation presented in Chapter 1.

As discussed in Chapter 5, respondents must accept the policy context provided in the questionnaire and believe that their responses will inform future policies to reduce noise so that the stated preference survey can elicit the true preferences of respondents. This chapter identified two types of anomalous responses, namely, protest respondents and respondents who did not believe that the survey was consequential. In the field surveys, both types of anomalous respondents amounted to around a quarter of the sample size, which is high as compared to other studies (see, for example, Meyerhoff & Liebe (2010) for a meta-analysis). The demographic characteristics that lead to a higher likelihood of these anomalous responses were examined. The relatively high rates of anomalous response may also have been caused by public sentiment. While this factor is not fully examined in this thesis, the ground sentiment in Singapore and its potential impact on the number of anomalous respondents in this survey are discussed in Section 12.2.1. In subsequent analysis, the differential effect of including and excluding these anomalous respondents from the sample is examined.

Chapters 8 to 11 use the regression techniques discussed in Chapter 4 to estimate the willingness-to-pay for construction and road noise reduction. Results of these regressions address the research questions presented in Chapter 3. Specific to the next chapter, Chapter 8, conditional and random parameter logit models will be used to estimate the willingness-to-pay for construction noise abatement. The estimated willingness-to-pay for construction noise abatement answers the Research Question (1). It also informs the marginal benefits function that can be used in a cost-benefit analysis of policies to reduce construction noise.

Chapter 8: Willingness-to-pay for Construction Noise Abatement

This chapter investigates Research Question (1): What is the willingness-to-pay for construction noise abatement? To answer this question, the data from the survey prepared in Chapters 5 and 6 were analysed with the methods discussed in Chapter 4, namely the conditional logit and random parameter logit models. The analysis estimates the preferences for a change in the physical measures of noise abatement (i.e., decibels) as construction noise policies are designed based on this measure of noise levels. The results from this chapter inform the marginal benefits of construction noise abatement, which can be used in the cost-benefit framework presented in Chapter 2.

As discussed in Chapter 4, the construction noise survey was conducted over two phases, namely a laboratory survey and a field survey. In Section 8.1, the results from the laboratory survey are presented and discussed. Section 8.2 discusses the results of the pilot field surveys, which provide information on the design of the main field survey questionnaire. Results from the main field survey are presented and discussed in Section 8.3. The estimated willingness-to-pay for construction noise abatement is also estimated in Section 8.3. Section 8.4 concludes the chapter with a discussion on the implications for future cost-benefit analysis of construction noise abatement policy.

8.1 Laboratory survey

8.1.1 Conditional logit regressions

This section presents the results of conditional logit regressions analysing the results from the laboratory survey.[63] Results of the conditional logit regressions are shown in Table 8-1. Specification (1) is the baseline regression that included all attributes in the choice model, which enables the estimation of a linear change in the public provision of noise abatement and other policy attributes.

As discussed in Chapter 5, each choice set presents respondents with 3 policy options, namely a status quo option and two unlabelled options that proposes changes to the status quo.

[63] Condition logit regressions were estimated with the clogit command in STATA.

Respondents may have different preferences for the status quo option as compared to the proposed changes to the status. Hence, an alternative specific constant (ASC) was included in the regression. Since the choice sets were unlabelled, the ASCs were defined to be dummy variables that take a value of zero for the status quo option and a value of one otherwise.

Systematic taste variation may affect preferences for noise abatement, so Specification (2) examines the effect of demographic and socio-economic variables on preferences for construction noise abatement policy. These variables also control for unobserved variation that is correlated with the attributes, accounting for omitted variable bias. In addition to the variables included in Specification (1), Specification (2) included variables that may affect respondents' preferences for noise abatement, including respondents' age, gender, ethnicity, household size, income, and whether the respondent lives in a private or public residence. These variables were interacted with the alternative specific constant as they do not vary within respondents and will be collinear if included directed in the regression.

Specification (3) is the preferred model. In Specification (3), the full set of control variables outlined in Specification (2) was included in the regression. The sample of this specification excluded 12 protest respondents.[64] As described in Sections 5.9.4 and 7.3.2, these respondents rejected the scenario presented in the survey questionnaire and did not reveal their true preferences when answering the choice sets. Exclusion of these respondents in the preferred specification ensured that the regression estimates were not biased by these anomalous respondents.

[64] In the laboratory survey, respondents who thought that the survey was inconsequential was not recorded due to an error in the coding of the survey questionnaire. Hence, only protest respondents were excluded.

Table 8-1 Conditional logit regressions on laboratory survey responses estimating the willingness-to-pay for construction noise abatement

	Conditional logit		
	(1)	(2)	(3)
Cost	-0.0107***	-0.0107***	-0.0108***
	(0.00143)	(0.00144)	(0.00145)
Reduction in noise level (dB)	0.0474***	0.0474***	0.0476***
	(0.00648)	(0.00649)	(0.00654)
Work prohibited on weekends	0.141	0.141	0.141
and public holidays	(0.106)	(0.106)	(0.108)
Work prohibited on weekends,	0.420***	0.420***	0.428***
eves and public holidays	(0.104)	(0.105)	(0.107)
Reduction in duration of	0.0359***	0.0359***	0.0362***
construction activity (in month)	(0.00408)	(0.00408)	(0.00412)
Change in start time of	-0.00770	-0.00767	-0.00677
construction activity (per hour later)	(0.0251)	(0.0251)	(0.0255)
Change in end time of	0.0525**	0.0525**	0.0517**
construction activity (per hour earlier)	(0.0216)	(0.0216)	(0.0219)
Alternative specific constant (ASC)	0.0591	0.0779	-0.00745
	(0.164)	(0.395)	(0.450)
Control variables			
Age		0.00923	0.0186***
		(0.00577)	(0.00676)
Female		-0.162	-0.363**
		(0.135)	(0.161)
Malay		-0.297	-0.363
		(0.215)	(0.260)
Indian		-0.138	-0.624***
		(0.227)	(0.236)
Other		2.508**	2.029**
		(1.020)	(1.022)
Household size		-0.0613	0.0183
		(0.0552)	(0.0647)
Income		-0.00164	-0.00884
		(0.0187)	(0.0223)
Private housing		-0.236	-0.177
		(0.184)	(0.218)
Log-likelihood	-1289.8	-1278.0	-1123.3
McFadden pseudo R^2	0.089	0.097	0.142
AIC	2595.6	2588.0	2278.6
BIC	2645.6	2688.2	2377.5
No. of observations	3576	3576	3576
No. of respondents	149	149	149

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: A full description of the attributes and levels is provided in Section 6.4.3.1. Control variables were interacted with the ASC. Age, Income, and Household size were continuous variables representing respondent's age, income, and household size respectively. All other control variables were dummy variables. Female was assigned a value of one if the respondent was female. The ethnicity variables, Malay, Indian, and Other, were assigned a value of one if a respondent was that particular ethnicity. Other also took a value of one if the respondent did not state their ethnicity. The base ethnicity was Chinese. Private housing took a value of one if the respondent lives in private housing. The base housing type was public housing.

Three criteria were used to compare the performance of the different specifications, namely, the McFadden pseudo R^2, the Akaike Information Criterion (AIC), and the Bayesian Information Criterion (BIC) (Akaike 1998; McFadden 1974; Schwarz 1978). The McFadden pseudo R^2 is defined to be:

$$R^2 = 1 - \frac{LL_{model}}{LL_{null}} \tag{8–1}$$

where LL_{model} is the log-likelihood of the regression model and LL_{null} is the log-likelihood of the model without any explanatory variables. Likelihoods of models are bounded by zero and one, hence the log-likelihood is bounded above by zero. Models with low likelihood will have a more negative log-likelihood as compared to models with high likelihood. Hence, a small ratio of log-likelihood indicates that the regression model performs better than the intercept model. As such, McFadden pseudo R^2 increases as the fit of a model improves.

The AIC is described to be:

$$\text{AIC} = 2\text{k} - 2LL_{model} \qquad (8\text{–}2)$$

where k is the number of parameters estimated by the model and LL_{model} is the log-likelihood of the regression model. The AIC penalises the inclusion of k parameters by $2k$. If this penalty is offset by the decrease in log-likelihood due to the inclusion of the variables in the regression, then the AIC falls. Consequently, models with lower AIC are favoured over models with higher AIC.

The BIC is similar to the AIC, with the exception that the penalty of including k parameters is $\ln(n)\,k$, where n is the number of observations. Hence, the BIC is defined to be:

$$\text{BIC} = \ln(n)\,k - 2LL_{model} \qquad (8\text{–}3)$$

Similar to the AIC, models with lower BIC are favoured over models with higher BIC.

Inclusion of more control variables improved the performance of the model. Comparing Specifications (1) and (2) of Table 8-1, the McFadden pseudo R^2 increased and the AIC decreased with the inclusion of more control variables, indicating that inclusion of control variables improved the fit of the model. Further, F-tests on the joint significance of control variables were also found to be statistically significant at the 1% level of significance.

The preferred model, Specification (3), which included a full set of control variables and excluded anomalous responses, has the highest McFadden pseudo R^2 and lowest AIC and BIC among the three specifications. As such, exclusion of anomalous responses in Specification (3) provided a better fit of the data as compared to Specification (2).

Notwithstanding the performance of the conditional logit models, the estimated coefficients of the attributes were similar across Specifications (1) to (3). The Hausman test is commonly used to test the equivalence of full and restricted models (Hausman & McFadden 1984). The Hausman test statistic is given by:

$$\left(\widehat{\beta^{r}} - \widehat{\beta^{f}}\right)^{T}\left(\widehat{Var}\left(\widehat{\beta^{r}}\right) - \widehat{Var}\left(\widehat{\beta^{f}}\right)\right)\left(\widehat{\beta^{r}} - \widehat{\beta^{f}}\right) \tag{8–4}$$

where $\widehat{\beta^{r}}$ are the estimates from the restricted model, $\widehat{\beta^{f}}$ are the estimates from the full model. $\widehat{Var}(\cdot)$ are the estimated variances from the respective model.

A limitation of the Hausman test statistic is that the difference in variance may not be positive semi-definite, leading to a test statistic that is negative (Cheng & Long 2007; Hausman & McFadden 1984). A negative test statistic cannot be compared with the χ^2 distribution, which only takes positives values. Specific to the regressions in Table 8-1, when Specifications (1) and (2) were tested against Specification (3), the test statistics were -0.46 and -94.45 respectively. Hausman & McFadden (1984) suggests that a negative test statistic provides evidence that the full and restricted models were not statistically different.

The seemingly unrelated estimation procedure in STATA (the suest package) is a generalisation of the Hausman test. In a seemingly unrelated estimation, the difference in variance was estimated with $\widehat{Var}\left(\widehat{\beta^{r}}\right) - \widehat{cov}\left(\widehat{\beta^{r}}, \widehat{\beta^{f}}\right) - \widehat{cov}\left(\widehat{\beta^{f}}, \widehat{\beta^{r}}\right) + \widehat{Var}\left(\widehat{\beta^{f}}\right)$, which results in an estimator that is always admissible and the test is always well defined (STATA 2017).

When a seemingly unrelated estimation was conducted, no evidence was found to indicate that the coefficients of each attribute were statistically different across all specifications. The *p*-values of the tests were all larger than 0.1, indicating that the null hypothesis of equality of the coefficients across all specifications cannot be rejected. Results of the seemingly unrelated estimation are shown in Table 8-2. These results indicate that the estimates were robust to the inclusion of additional demographic and socio-economic variables, and the exclusion of anomalous responses.

Table 8-2 Seemingly unrelated estimation tests for equality of coefficients across all specifications

	Test results Specification 1 coefficient = Specification 2 coefficient = Specification 3 coefficient	
	χ^2	*p*-value
Cost	0.16	0.9218
Reduction in noise level (dB)	0.03	0.9829
Work prohibited on weekends and public holidays	0.00	0.9999
Work prohibited on weekends, eves and public holidays	0.10	0.9502
Reduction in duration of construction activity (in month)	0.35	0.8405
Change in start time of construction activity (per hour later)	0.05	0.9773
Change in end time of construction activity (per hour earlier)	0.06	0.9701

In the preferred specification, namely Specification (3) of Table 8-1, the signs on the regression coefficients of the attributes were as expected *a priori*. First, the cost attribute was negative and statistically significant, indicating that an increase in costs is associated with a fall in the probability that an alternative will be chosen. Second, the coefficient on reduction in noise levels was positive, demonstrating a preference for reduced noise levels. Third, the estimated coefficients on the days when construction activity are prohibited were also positive. However, the coefficient on the extension of the prohibition of construction activity to Saturdays was not statistically different from zero at the 10% level of confidence. Further, this coefficient was also lower than the coefficient on extending the prohibition to Saturdays and eve of public holidays, possibly due to the dominance of the former over the latter. When a one-sided *z*-test was conducted, the difference between these two coefficients was statistically significant at the 1% level of significance. Fourth, the coefficients on the reduction in duration of construction activity were positive, suggesting that respondents preferred shorter construction duration.

The coefficient on the end time of construction activity was positive and statistically different from zero, indicating that respondents valued construction activity ending earlier. Respondents' preference for an earlier end to construction activity was in line with the intuition that respondents will likely return home from work in the evenings and noise from construction activity cause disamenities when they are home. By comparison, no evidence was found at the 10% level of statistical significance that the coefficient on start time was different from zero, suggesting that respondents had no preference for changes to the start time of construction activity. This result may have been due to the smaller sample size of the laboratory survey as compared to later phases, which can lead to lower statistical significance on the estimated coefficients.

In the preferred specification, the alternative specific constant (ASC) was not found to be statistically significant. The ASCs represents the average effect of unobserved sources of utility (Hensher, Rose & Greene 2015). As such, the regression results suggest that there were unobserved sources of heterogeneity which are correlated with the control variables.

Control variables were included in the regression by interacting the control variables with the ASC. In the preferred specification, older respondents were found to be more likely to choose alternatives that proposed changes to the status quo. Conversely, females were more likely to choose the status quo option. Ethnicity was found to influence respondents' preferences. Indian respondents were more likely to choose the status quo option and respondents with ethnicities other than Chinese, Malay, and Indian were less likely to choose the status quo as compared to other alternatives. Only 3% of respondents were categorised as other ethnicities and the preferences for other ethnicities may be driven by a small sample of respondents. In the preferred specification, household size, income and dwelling type of respondents were not statistically significant. However, these variables were included as they can potentially affect the choices of respondents.

The results in Table 8-1 can be used to estimate the willingness-to-pay for each attribute. Table 8-3 presents the estimated willingness-to-pay for the preferred specification (i.e., Specification (3)). As discussed in Section 4.1.4, the willingness-to-pay was estimated by taking the ratio of each attribute to the cost attribute. The confidence intervals of each attribute were estimated with the Krinsky-Robb parametric bootstrap method (Krinsky & Robb 1986).[65]

Table 8-3 Willingness-to-pay for the attributes in Specification (3) of Table 8-1

	Willingness-to-pay (S$)	90% Confidence interval
Reduction in noise level (per dB reduction)	4	(3, 6)
Work prohibited on weekends and public holidays	–	
Work prohibited on weekends, eves and public holidays	40	(23, 59)
Reduction in duration of construction activity (in months)	3	(3, 4)
Change in start time of construction activity (per hour later)	–	
Change in end time of construction activity (per hour earlier)	5	(1, 9)

Note: Statistically insignificant variables were suppressed.

The estimated willingness-to-pay for a 1dB reduction in noise was estimated to be a one-off payment of S$4 per dB for each respondent on average from the baseline of 75dB.[66] This estimate was statistically different from zero at the 10% level of significance. The

[65] The willingness-to-pay was estimated with wtp package in STATA.

[66] As discussed in 6.4.2, respondents were asked about individual willingness-to-pay as some respondents may not know the preferences of all members in their household.

estimated willingness-to-pay for the prohibition of construction work on Saturdays, Sundays, eve of public holidays and public holidays was around S$40. In comparison with the reduction to noise levels, prohibiting construction work on weekends, eves, and on public holidays is equivalent to around a 10dB reduction in noise levels. Respondents also indicated that they were willing to pay on average a one-off payment of S$3 for a one month decrease in construction activity and S$5 for each hour earlier construction activity is mandated to end.

8.1.2 Random parameter logit regression

As discussed in Section 4.1.2, the conditional logit model assumes that the unobserved component of utility is independently and identically distributed (IID). In order to relax the IID assumptions, a random parameter logit regression was also estimated. This specification allows for heterogeneity of preferences of some variables. In order to model this preference heterogeneity, the distribution needs to be imposed on the random parameters. Given that the direction of preference is not known *a priori*, a normal distribution was assumed, allowing parameters to take on both positive and negative values.

Results of the random parameter logit are shown in Table 8-4.[67] All non-cost attributes in the choice model were treated as random parameters as respondents' preferences for these attributes may vary heterogeneously.[68] The attributes were assumed to be normally distributed as the direction of respondents' preferences for these attributes were not known *a priori*. The regression included the same set of control variables included in the preferred specification presented in Table 8-1. As discussed in Section 8.1.1, the demography and socio-economic variables were included in the regression to control for systematic taste variable, which can occur in addition to the random taste variable that is accounted for by the random parameter logit model. Anomalous respondents were also excluded from the random parameter logit to ensure that these respondents do not affect regression estimates.

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[67] The random parameter logit regressions were estimated with the mixlogit regression package in STATA. See Hole (2007b) for details on the mixlogit package. To implement the random parameter logit, the mixlogit command was first estimated with 50 repetitions. The estimates from this run were then used as initial estimates for a second run which used 1000 repetitions.

[68] The cost attribute was specified as a fixed parameter as specifying the cost attribute as a random parameter tended to increase the standard deviation of the estimated willingness-to-pay. Nonetheless, the point estimates of the willingness-to-pay were not statistically different from the results presented in this section.

Table 8-4 Random parameter logit regressions on laboratory survey responses to estimate the willingness-to-pay for construction noise abatement

	Random parameter logit	
	(1)	
	Mean	Standard deviation
Attributes		
Random parameters		
Reduction in noise level (dB)	0.0505***	0.108***
	(0.0126)	(0.0119)
Work prohibited on weekends and public holidays	0.120	0.483**
	(0.139)	(0.202)
Work prohibited on weekends, eves and public holidays	0.527***	0.0939
	(0.133)	(0.328)
Reduction in duration of construction activity (in month)	0.0502***	0.0431***
	(0.00654)	(0.00794)
Change in start time of construction activity (per hour later)	-0.0228	0.247***
	(0.0373)	(0.0507)
Change in end time of construction activity (per hour earlier)	0.0588*	0.247***
	(0.0345)	(0.0442)
Fixed parameters		
Cost	-0.0142***	
	(0.00179)	
Alternative specific constant (ASC)	0.154	
	(0.774)	
Control variables		
Age	0.0285**	
	(0.0121)	
Female	-0.403	
	(0.286)	
Malay	-0.672	
	(0.479)	
Indian	-0.956**	
	(0.441)	
Other	1.308	
	(1.224)	
Household size	0.0874	
	(0.114)	
Income	-0.0328	
	(0.0398)	
Private housing	-0.340	
	(0.380)	
Log-likelihood	-1009.2	
McFadden pseudo R^2	0.229	
AIC	2062.4	
BIC	2198.4	
No. of observations	3576	
No. of respondents	149	

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.
Note: Control variables were interacted with the ASC. Control variables were treated as fixed variables. Definitions of variables are the same as those used in Table 8-1. Standard deviations are given for random parameters. All random parameters were assumed to have a normal distribution.

The random parameter logit provided a better fit as compared to the conditional logit regressions. As compared to Specification (4) in Table 8-1, the random parameter logit had lower AIC and BIC, indicating that the random parameter logit specification minimised estimated information loss as compared to the conditional logit specification. Further, the McFadden pseudo R^2 was also higher in the random parameter logit as compared to the conditional logit model. When a Hausman test was conducted to test the equivalence of the conditional logit and random parameter logit models, the test statistic was 37.84 (*p*-value of 0.0016).[69] This indicates that the null hypothesis that the difference in coefficients was not systematic can be rejected and the estimates from the random parameter regression were preferred.

Coefficients from the random parameter logit regression were as expected. The cost attribute was negative and statistically significant, indicating that respondents preferred lower cost options. The estimated means of statistically significant non-costs attributes were all positive, indicating that respondents were willing to pay for a tightening of noise abatement regulations. While the estimated means of an extension of work prohibition to weekends and public holidays and later start times were not statistically significant, the estimated standard deviations of these variables were statistically significant, indicating heterogeneous preferences for these variables in the survey sample.

With the exception for preferences prohibiting construction work on weekends, eves, and public holidays, the random parameter logit regression found evidence that respondents' preferences for the duration of construction activity were heterogeneous. The standard deviations of these variables were found to be statistically different from zero at the 1% level of significance, indicating that respondents have different preferences for changes to these attributes.

The mean of the ASC in the random parameter logit model was statistically insignificant, suggesting that unobserved components of utility did not influence respondents' preferences.

Results of the random parameter logit regression can also be used to estimate the average willingness-to-pay for each attribute. These willingness-to-pay estimates are shown in Table 8-5. On average, respondents were willing to pay a one-off payment of S$4 to reduce construction noise by one-decibel. Respondents' willingness-to-pay to extend the prohibition of construction work to Saturdays and eves of public holidays was a one-off payment of S$36 on average. Average willingness-to-pay for a one-month reduction of construction noise and a one-hour earlier end to construction activity were both one-off payments of S$4.

[69] A seemingly unrelated estimation was not conducted as a random parameter logit does not follow a standard variance-covariance structure.

Table 8-5 Willingness-to-pay for the attributes described in Table 8-4

	Willingness-to-pay (S$)	90% Confidence interval
Reduction in noise level (per dB reduction)	4	(2, 6)
Work prohibited on weekends and public holidays	–	
Work prohibited on weekends, eves and public holidays	36	(21, 55)
Reduction in duration of construction activity (in months)	4	(3, 5)
Change in start time of construction activity (per hour later)	–	
Change in end time of construction activity (per hour earlier)	4	(0, 9)

Note: Statistically insignificant variables were suppressed.

8.2 Pilot field surveys

Following the laboratory survey, pilot field surveys were conducted. The field survey differed from the laboratory survey in three aspects. First, respondents surveyed in the field were drawn from a sample provided by Singapore's Department of Statistics and were interviewed on the doorsteps of their homes.[70] Consequently, respondents to the field survey did not need to travel to the survey company's premises to complete the survey. Since the profile of an individual who was willing to travel to participate in the survey might be different from individuals who were unwilling to travel, the field survey likely captured a larger segment of the population.

Second, field survey respondents could directly perceive the background noise level. By comparison, in the laboratory survey, respondents were in a quiet environment and were not exposed to environmental noise when completing the survey. Since background levels of noise may affect a respondent's preferences for noise abatement, estimates from the laboratory survey may differ from the field survey.

Third, respondents to the laboratory completed the survey questionnaire while seated in an air-conditioned conference room. In contrast, the field survey respondents typically completed the survey questionnaire standing on the doorstep of their homes. Consequently, respondents to the laboratory survey enjoyed more comfort when completing the survey questionnaire as compared to the field survey respondents.

As discussed in Section 6.4.2, two pilot field surveys were conducted. In the first pilot field survey, respondents were presented with a compulsory one-off contribution to a community fund. In the second pilot field survey, respondents were presented with mandatory annual payments to the community fund. The results of the pilot surveys are discussed in turn.

[70] As discussed in Section 4.3, it is a cultural custom for short surveys to be completed at respondents' doorsteps in Singapore.

8.2.1 *First pilot field survey*

Results of the first pilot survey are shown in Table 8-6. In Specifications (1) and (2), the full sample of the first pilot survey was used in the regression. Anomalous respondents were excluded in Specifications (3) and (4). Anomalous respondents are defined to be protest respondents and respondents who did not think that the results of the survey will inform future policies on noise abatement. In total, 34 respondents were excluded from the regression sample of Specifications (3) and (4). In Specification (1) and (3) a linear functional form was used to describe changes in noise levels, while Specifications (2) and (4) used dummy variables for each level of noise reduction.

Table 8-6 Conditional logit regressions on pilot field survey 1 to estimate the willingness-to-pay for construction noise abatement

	Conditional logit			
	(1)	(2)	(3)	(4)
Cost	-0.00540***	-0.00469**	-0.00483***	-0.00541**
	(0.000853)	(0.00207)	(0.000878)	(0.00262)
Reduction in noise level (dB)	-0.0167*		-0.0166	
	(0.01000)		(0.0106)	
5db reduction		0.102		0.841***
		(0.201)		(0.229)
10db reduction		-0.101		0.894
		(0.446)		(0.547)
15db reduction		-0.0273		0.680***
		(0.201)		(0.241)
20db reduction		-0.283		0.700
		(0.420)		(0.522)
Work prohibited on weekends	0.0106	0.0202	0.0286	0.0256
and public holidays	(0.143)	(0.145)	(0.156)	(0.157)
Work prohibited on weekends,	-0.160	-0.221	-0.163	-0.107
eves and public holidays	(0.141)	(0.210)	(0.154)	(0.274)
Reduction in duration of	0.0109*	0.00466	0.00759	0.0128
construction activity (in month)	(0.00578)	(0.0172)	(0.00614)	(0.0228)
Change in start time of	-0.0336	-0.0355	-0.0478	-0.0458
construction activity (per hour later)	(0.0351)	(0.0342)	(0.0374)	(0.0368)
Change in end time of	0.0547	0.0527	0.0518	0.0527
construction activity (per hour earlier)	(0.0336)	(0.0349)	(0.0356)	(0.0369)
Alternative specific constant (ASC)	0.197		0.934***	
	(0.224)		(0.250)	
Log-likelihood	-832.3	-832.2	-582.2	-582.2
McFadden pseudo R^2	0.081	0.081	0.040	0.040
AIC	1680.5	1684.3	1180.4	1184.4
BIC	1727.0	1742.5	1223.7	1238.5
No. of observations	2472	2472	1656	1656
No. of respondents	103	103	69	69

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.
Note: The ASC was omitted in Specifications (2) and (4) as it was collinear with the dummies for a reduction in noise levels.

Several estimates from the conditional logit regressions on the first pilot survey were counter-intuitive. In Specification (1), the coefficient for the cost variable was statistically significant and negative, in line with the intuition that respondents were less likely to choose an alternative if the cost of that alternative was higher. However, the coefficient on the reduction of noise levels was negative and statistically significant, indicating that alternatives with lower noise levels were less preferred. In other words, respondents' willingness-to-pay for noise abatement was negative. Respondents also indicated a preference for shorter construction duration. All other attributes were not statistically significant.

In Specification (2), the cost variable was still statistically significant and negative. However, no evidence was found to indicate that any of the other variables were statistically different from zero. This result may be due to the large proportion of anomalous responses. Excluding 34 anomalous respondents in Specification (3), the cost variable remained statistically significant and negative. However, the coefficients of all other attributes were not statistically significant.

Excluding protest respondents and using dummy variables for each noise level in Specification (4) results in the cost variable remained negative and statistically different from zero. The coefficients on each of the dummy variables were statistically significant and positive, suggesting that respondents preferred a 5dB or 15dB reduction in noise levels from the baseline noise level of 75dB.

The results from the first pilot survey may have been due to several reasons. First, respondents to the field survey completed the survey questionnaire in a less comfortable environment as compared to laboratory survey respondents. Further, in the first pilot survey, the survey company included several questions at the start of the survey questionnaire to contact the respondent, such as questions on the respondent's address, telephone number (including mobile and home numbers), and the name of the respondent. While answers to these questions were straightforward, it was necessary to manually type in the responses to each of these questions. For example, the address of a typical respondent comprises of the street name, block number, unit number, and postal code. Since respondents were most likely standing at the entrance to their homes, the time needed to complete these questions may have increased survey fatigue.

Second, as discussed in Section 6.4.2, approximately an equal proportion of focus group discussion participants expressed a preference for an annual payment and a one-off payment to a community fund as the payment vehicle. Respondents to the pilot survey may have preferred the annual payment to the community fund. To explore the differential effects of payment interval on respondents' preferences for noise abatement, a second pilot survey was conducted.

8.2.2 Second pilot field survey

A second pilot field survey was conducted. In this pilot, all demography questions were moved to the end of the survey questionnaire. Where possible, the surveyor completed these questions on behalf of the respondents to reduce survey fatigue. For example, the respondent's address was known to the surveyor and was completed by the surveyor. Further, the payment vehicle used in the second pilot was an annual payment to a community fund. Respondents were informed that this annual payment would be made for three years, which is the approximate duration of construction to complete a new development in Singapore.

Results of the second pilot are presented in Table 8-7. Similar to the first pilot, four regressions were estimated, namely, regressions with linear functional forms on changes in noise levels (Specifications (1) and (3)), and dummy variables for each level of noise reduction (Specifications (2) and (4)). In Specifications (1) and (2) were estimated with the full sample from the second pilot survey. Specifications (3) and (4) excluded 35 anomalous respondents.

Table 8-7 Conditional logit regressions on pilot field survey 2 to estimate the willingness-to-pay for construction noise abatement

	Conditional logit			
	(1)	(2)	(3)	(4)
Cost	-0.00366***	-0.00362***	-0.00413***	-0.00408***
	(0.00107)	(0.00107)	(0.00125)	(0.00126)
Reduction in noise level (dB)	-0.0251**		-0.0246*	
	(0.0118)		(0.0133)	
5db reduction		-0.158		0.610***
		(0.205)		(0.234)
10db reduction		-0.200		0.621***
		(0.191)		(0.215)
15db reduction		-0.450*		0.356
		(0.265)		(0.316)
20db reduction		-0.504**		0.280
		(0.221)		(0.254)
Work prohibited on weekends	-0.289*	-0.283*	-0.289	-0.280
and public holidays	(0.164)	(0.164)	(0.182)	(0.182)
Work prohibited on weekends,	-0.475***	-0.495***	-0.493***	-0.518***
eves and public holidays	(0.166)	(0.170)	(0.188)	(0.193)
Reduction in duration of	0.0343***	0.0351***	0.0369***	0.0380***
construction activity (in month)	(0.00616)	(0.00627)	(0.00670)	(0.00686)
Change in start time of	-0.0681*	-0.0675*	-0.0780*	-0.0771*
construction activity (per hour later)	(0.0409)	(0.0409)	(0.0429)	(0.0431)
Change in end time of	0.0214	0.0363	0.0343	0.0515
construction activity (per hour earlier)	(0.0377)	(0.0463)	(0.0400)	(0.0505)
Alternative specific constant (ASC)	0.0169		0.811***	
	(0.205)		(0.223)	
Log-likelihood	-735.9	-735.7	-527.9	-527.8
McFadden pseudo R^2	0.163	0.163	0.076	0.076
AIC	1487.8	1491.5	1071.9	1075.5
BIC	1534.0	1549.3	1114.7	1129.0
No. of observations	2400	2400	1560	1560
No. of respondents	100	100	65	65

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: The ASC was omitted in Specifications (2) and (4) as it was collinear with the dummies for a reduction in noise levels.

Across Specifications (1) to (4), the coefficients for the cost attribute were negative and statistically significant, indicating that respondents preferred alternatives that were less expensive. The point estimate on the reduction of noise levels in Specifications (1) and (3) were still negative and in Specification (1), this estimate was statistically significant.

In Specification (2), the dummy variables on noise levels were negative, likely due of the large proportion of anomalous respondents. By comparison, when anomalous respondents were excluded in Specification (4), the dummy variables on 5dB and 10dB reductions from the baseline noise level of 75dB were positive and statistically significant.

The attributes on the days when construction activity was prohibited were negative in Specifications (1) and (2), which suggests that respondents were averse to the extension of days when construction activity was prohibited. This result was counter-intuitive as respondents should prefer less noise from construction activity on weekends and eve of public holidays. Exclusion of anomalous respondents resulted in the estimates on these attributes becoming insignificant, suggesting that the results in Specifications (1) and (2) may have been influenced by these anomalous responses.

Across all specifications, the coefficient on the reduction of the duration of construction activity was positive and statistically significant, indicating that respondents preferred shorter durations. However, the coefficients on later start times were negative and statistically significant, which indicates that respondents preferred earlier start times. Further, the coefficients on end times were not statistically significant. These results may have been due to the small sample size in the pilot survey and further insight can be gleaned from analysis of the data obtained from the main field survey.

Comparing results from the first and second pilot surveys, Specification (4) of both surveys was the only Specification where the coefficients of the noise abatement variables were positive and statistically significant. In Specification (4) of both pilot surveys, the willingness-to-pay for a 5dB reduction in construction noise was the only noise abatement attribute that was statistically significant in both regressions. In the first pilot survey, the estimated willingness-to-pay was S$155 (95% confidence interval: S$43 to S$667). In the second pilot survey, the estimated willingness-to-pay was S$149 (95% confidence interval: S$39 to S$339).

Full combinatorial Poe tests[71] on these estimates indicate that these variables were not statistically different. This result is counter-intuitive since respondents should be willing to pay less on an annual basis as compared to a one-off payment. The result suggests that respondents may not be discounting future benefits of noise abatement when a one-off payment vehicle was used. Hence, the annual payment vehicle was used in the main audio- and text-based field survey.

8.3 Main field survey

Following the pilot surveys, the main field survey was conducted. The finalised field survey questionnaire was similar to the questionnaire used in the second phase of the pilot survey. All demography questions (e.g., respondent's address and phone numbers) were only asked at the end of the survey questionnaire. Further, the payment vehicle used in the final survey questionnaire was an annual payment to a community fund as opposed to the one-off payment used in the laboratory survey.

The main difference between the second pilot and the main survey questionnaires was the combination of levels presented to respondents in each choice set. Priors used in the efficient design of the main survey questionnaire were obtained from Specification (3) of Table 8-7. Negative non-cost attributes were replaced with coefficients obtained from the laboratory survey, (i.e., Specification (3) of Table 8-1).

8.3.1 Conditional logit regressions

The results of the conditional logit regressions are shown in Table 8-8. Similar to the results presented in Table 8-1, Specifications (1) and (2) were estimated on the sample obtained from the main survey. Specification (1) estimated the linear preferences for each attribute. Further, an alternative specific constant was included. The alternative specific constant took a value of zero for the status quo option and one otherwise.

Specification (2) accounted for systematic variation in tastes with the inclusion of demographic and socio-economic variables. These variables include respondents' age, gender, ethnicity, household size, income and dwelling type. These variables were included as they can potentially affect respondents' preferences for noise abatement.

[71] The bootstrap iterations from the Krinsky-Robb method were saved and the mded package in R was used to conduct the Poe tests.

Specification (3) excluded 297 anomalous respondents (37% of the sample). Similar to the pilot field surveys, these anomalous respondents were defined to be protest respondents and respondents who thought that the survey questionnaire was not consequential. These respondents were excluded as they may have rejected the policy scenario presented in the survey and may not have revealed their true preferences. Specification (3) is the preferred regression model as a full set of controls were included and anomalous respondents who could bias the results were excluded.

Table 8-8 Conditional logit regressions on the main field survey to estimate the willingness-to-pay for construction noise abatement

	Conditional logit		
	(1)	(2)	(3)
Cost	-0.00382***	-0.00385***	-0.00410***
	(0.000298)	(0.000298)	(0.000323)
Reduction in noise level (dB)	0.0581***	0.0587***	0.0709***
	(0.00345)	(0.00346)	(0.00391)
Work prohibited on weekends	0.300***	0.296***	0.197***
and public holidays	(0.0562)	(0.0565)	(0.0645)
Work prohibited on weekends,	0.361***	0.361***	0.306***
eves and public holidays	(0.0578)	(0.0581)	(0.0666)
Reduction in duration of	0.0208***	0.0208***	0.0213***
construction activity (in month)	(0.00202)	(0.00202)	(0.00217)
Change in start time of	0.0308**	0.0312**	0.0500***
construction activity (per hour later)	(0.0128)	(0.0129)	(0.0153)
Change in end time of	0.00620	0.00667	0.0240*
construction activity (per hour earlier)	(0.0124)	(0.0124)	(0.0136)
Alternative specific constant (ASC)	-1.316***	-1.382***	-0.510***
	(0.0776)	(0.136)	(0.171)
Control variables			
Age		-0.00804***	-0.00669***
		(0.00167)	(0.00225)
Female		0.0925*	-0.0771
		(0.0530)	(0.0758)
Malay		0.0631	-0.437***
		(0.0810)	(0.100)
Indian		0.716***	0.473***
		(0.0924)	(0.130)
Other		-0.0681	-0.277
		(0.146)	(0.198)
Household size		0.0215**	0.000592
		(0.00844)	(0.00866)
Income		0.0964***	0.152***
		(0.0120)	(0.0195)
Private housing		-0.0402	0.764***
		(0.0741)	(0.141)
Log-likelihood	-6304.8	-6203.5	-3936.8
McFadden pseudo R^2	0.103	0.118	0.109
AIC	12625.7	12439.0	7905.7
BIC	12688.6	12564.8	8024.0
No. of observations	19200	19200	12072
No. of respondents	800	800	503

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.
Note: Control variables were interacted with the ASC. Definitions of variables are the same as those used in Table 8-1.

The inclusion of more control variables improved the performance of the model. Comparing Specifications (1) and (2) of Table 8-8, the inclusion of more control variables was associated with an increase in the McFadden pseudo R^2 and a decrease of both the AIC and the BIC. Further, F-tests on the joint significance of control variables were also found to be statistically significant at the 1% level of significance. These statistics suggest that the inclusion of demographic and socio-economic variables improved the performance of the models. When anomalous respondents were omitted in Specification (3), the AIC and BIC were both lower as compared to Specification (2). As such, based on the AIC and BIC, exclusion of protest votes further improved the performance of the conditional logit models.

When Specifications (1) and (2) were compared with the preferred specification with the Hausman test, the test statistics were -85.55 and -1495.3 respectively. As the test statistics were negative, a seemingly unrelated estimation procedure was used to test the equivalence of coefficients from the regressions. Test results are presented in Table 8-9. Except for the coefficient on reduction in construction duration, the coefficients in Specification (1) and (2) were statistically different from Specification (3). Results of these tests partly justify the use of Specification (3) as the preferred specification as Specification (3) included a full set of control variables and excluded anomalous respondents.

Table 8-9 Seemingly unrelated estimation tests for equality of coefficients across all specifications

	Test results			
	Specification 1 = Specification 3		Specification 2 = Specification 3	
	χ^2	*p*-value	χ^2	*p*-value
Cost	4.36	0.0367	3.52	0.0607
Reduction in noise level (dB)	43.36	0.0000	40.75	0.0000
Work prohibited on weekends and public holidays	11.68	0.0006	11.18	0.0008
Work prohibited on weekends, eves and public holidays	2.90	0.0884	2.97	0.0849
Reduction in duration of construction activity (in month)	0.41	0.5231	0.36	0.5467
Change in start time of construction activity (per hour later)	4.98	0.0256	4.86	0.0274
Change in end time of construction activity (per hour earlier)	8.18	0.0042	7.98	0.0047

The regression coefficients of the preferred specification were as expected *a priori*. First, the cost attribute was statistically significant at the 1% level of significance. The negative coefficient on the cost attribute indicates that respondents preferred lower cost options. Second, the estimated coefficient on the reduction of noise levels was positive, indicating that respondents preferred options with lower noise levels. Third, the estimated coefficients on the days when construction activity was prohibited are both positive. Further, the coefficient on the extension of the prohibition of construction activity to Saturdays was lower as compared to the coefficient on the extension of the prohibition to Saturdays and eves of public holidays, likely due to the dominance of the latter over the former. This difference was statistically significant at the 5% level of significance. Fourth, the coefficient on the reduction in duration of construction activity was positive, indicating that respondents preferred shorter construction durations. Finally, the coefficients on later start times and earlier end times were positive and statistically significant, indicating that respondents preferred construction activity to start later in the morning and end later in the evening.

In the preferred specification, the ASC was statistically significant and negative, indicating that respondents were more likely to choose the status quo alternative as compared to other alternatives. The statistically significant ASCs suggest that the regressions may not have fully accounted for all sources of unobserved utility.

Control variables were included in the regression by interaction with the ASC. Older respondents were more likely to choose the status quo option. Ethnicity also influenced respondents' preferences. Malays were more likely to choose the status quo option, while Indians were less likely to choose the status quo option. Respondents with higher income and lived in private housing were more likely to choose options that proposed changes to the status quo.

8.3.2 Willingness-to-pay and policy implications

Regression results in Table 8-8 were used to estimate the willingness-to-pay for each attribute. Table 8-10 presents the estimated willingness-to-pay for the attributes for the preferred specification. The Krinsky-Robb parametric bootstrap method was used to estimate the confidence interval for each willingness-to-pay estimate. The estimated willingness-to-pay for a 1dB reduction in construction noise was estimated to be an annual payment of S$17 per dB over the course of three years. Assuming a 5% discount rate, the present value of this contribution is S$48.[72]

Table 8-10 Willingness-to-pay for the attributes in Specification (4) of Table 8-8

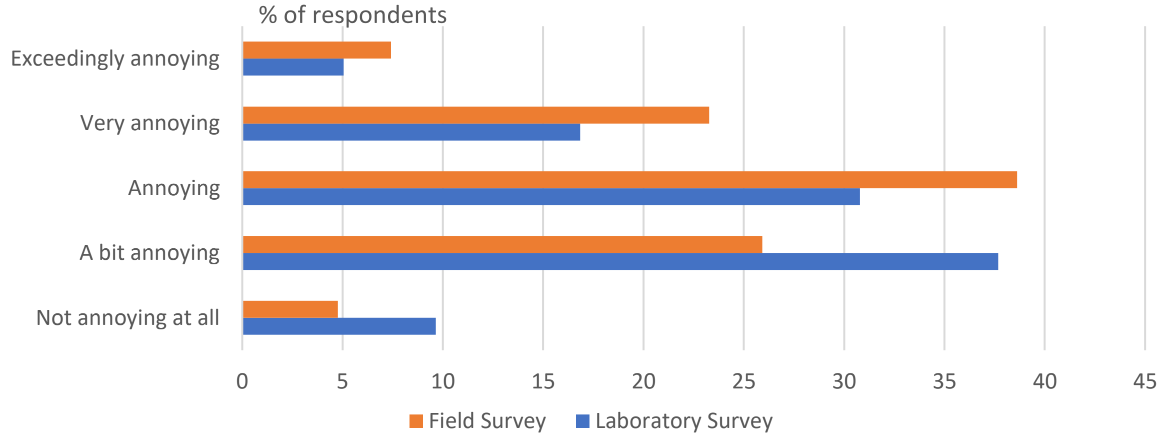
	Willingness-to-pay (S$)	90% Confidence interval
Reduction in noise level (per dB reduction)	17	(15, 20)
Work prohibited on weekends and public holidays	48	(22, 76)
Work prohibited on weekends, eves and public holidays	75	(49, 100)
Reduction in duration of construction activity (in months)	5	(4, 6)
Change in start time of construction activity (per hour later)	12	(7, 19)
Change in end time of construction activity (per hour earlier)	6	(1, 12)

Compared to the laboratory survey, the estimated willingness-to-pay for construction noise abatement was higher in the field survey. Assuming a 5% discount rate, the present value

[72] Use of a 5% discount rate is conservative. Singapore's risk-free rate, as estimated by 2-year and 5-year Singapore Government Securities is around 1.8% (Monetary Authority of Singapore 2019a). Giglio, Maggiori & Stroebel (2015) examined Singapore's housing market and estimated that long-run discount rates was 2.6%.

of respondents' willingness to pay for construction noise abatement was S S$48 per dB over the course of three years, compared to a one-off payment of S$4 per dB in the laboratory survey. The difference in willingness-to-pay may have been due to differences in the survey environment. The laboratory survey was completed in a quiet and controlled environment. By comparison, respondents to the field survey were exposed to ambient noise when completing the survey. Consequently, a larger proportion of field survey respondents reported that they were annoyed with construction noise (Figure 8-1). The increased annoyance may have in turn led to a higher willingness-to-pay.

Figure 8-1 Annoyance with construction noise, broken down by survey phase



Willingness-to-pay for the other attributes were also estimated. Similar to noise abatement, these willingness-to-pay refer to the amount each resident is willing to pay per annum over the course of three years. On average, respondents were willing to pay S$48 to extend the prohibition on construction activity to Saturdays. If the prohibition was further extended to eves of public holidays, the average willingness-to-pay increased to S$75. On average, respondents indicated that they were willing to pay S$5 per year for three years for each month construction activity was reduced. Respondents were willing to pay S$12 and S$6 per annum for three years for each hour construction activity is mandated to start and end respectively.

The results can be used to estimate the marginal benefits associated with a change in publicly provided noise abatement. For instance, consider a policy which results in the following changes to the status quo: a 5dB reduction in noise; prohibits construction activity on weekends, eves of public holidays and public holidays; and decreases the duration of construction activity by 3 months. The estimated average willingness-to-pay for this change in policy is S$175 per year for each respondent over the course three years (Table 8-11).

Table 8-11 Marginal benefits associated with a hypothetical change to construction noise control

Attribute	Change	WTP
Reduction in noise level	5dB	S$85
Work prohibited on weekends, eves and public holidays	Yes	S$75
Reduced duration of construction activity	3 months	S$15
	Total:	S$175

The overall benefits of the policy can be estimated by multiplying with the population that was adversely affected by construction noise and will benefit from the policy.

Suppose the government imposes the policy described in Table 8-11 on all construction sites. Assume that all working adults that are adversely affected by construction noise are willing to pay S$175 per year to implement this policy. The total resident labour force is 2.2 million (Statistics Singapore 2018b). Further, summary statistics in Section 7.1.2 indicate that 60% of this population is exposed to construction noise. Consequently, the estimated marginal benefits of the noise abatement policy are estimated to be S$231 million per year for three years.[73] Assuming that the discount rate is 5%, the present value of marginal benefits arising from this policy is S$659 million.

8.3.3 Random parameter logit regressions

A random parameter logit regression was estimated to relax the IID assumptions in the conditional logit regression. Results of the random parameter logit regression are shown in Table 8-12. Non-cost attributes were assumed to be normally distributed in the random parameter logit as the direction of preference for each of these attributes were not known *a priori*. A full set of controls similar to those in the preferred model from the conditional logit regression was included in the random parameter logit regression. 297 anomalous respondents, defined to be protest respondents and respondents who thought the survey was inconsequential, were excluded from the sample.

[73] If Singapore's total labour force (which includes foreigners) was used, the annual benefits associated with this policy will be $389 million per year. In total, Singapore's labour force was 3.7 million, comprising of 2.2 million citizens and permanent residents as well as 1.5 million foreigners (Statistics Singapore 2018b). The inclusion of foreigners in computation of the aggregate marginal benefits assumes that foreigners' willingness-to-pay for noise abatement is equivalent to that of locals.

Table 8-12 Random parameter logit regressions on field survey to estimate the willingness-to-pay for construction noise abatement

	Random parameter logit	
	(1)	
	Mean	Standard deviation
Attributes		
Random parameters		
Reduction in noise level (dB)	0.0477***	0.262***
	(0.0141)	(0.0157)
Work prohibited on weekends and public holidays	-0.126	0.0166
	(0.0856)	(0.261)
Work prohibited on weekends, eves and public holidays	0.303***	0.392***
	(0.0909)	(0.144)
Reduction in duration of construction activity (in month)	0.0312***	0.0379***
	(0.00343)	(0.00469)
Change in start time of construction activity (per hour later)	0.139***	0.141***
	(0.0237)	(0.0434)
Change in end time of construction activity (per hour earlier)	0.0564***	0.121***
	(0.0181)	(0.0358)
Fixed parameters		
Cost	-0.00730***	
	(0.000460)	
Alternative specific constant (ASC)	0.455	
	(0.346)	
Control variables		
Age	0.00338	
	(0.00509)	
Female	-0.0595	
	(0.165)	
Malay	-0.408*	
	(0.228)	
Indian	0.546**	
	(0.266)	
Other	-0.660	
	(0.461)	
Household size	-0.00725	
	(0.0286)	
Income	0.0337	
	(0.0397)	
Private housing	0.703***	
	(0.269)	
Log-likelihood	-2983.3	
McFadden pseudo R^2	0.325	
AIC	6010.5	
BIC	6173.3	
No. of observations	12072	
No. of respondents	503	

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: Control variables were interacted with the ASC. Control variables were treated as fixed variables. Definitions of variables are the same as those used in Table 8-1. Standard deviations are given for random parameters. All random parameters were assumed to have a normal distribution.

As compared to the conditional logit regressions in Table 8-8, the random parameter logit provided a better fit. The McFadden pseudo R^2 was higher in the random parameter logit while the AIC and BIC were both lower as compared to Specification (3) of Table 8-8. When a Hausman test was conducted, the test statistic was 360.45, with a corresponding *p*-value of 0.0000.

The signs of all statistically significant coefficients of attributes in the choice model were as expected *a priori*. The cost attribute was negative and statistically significant, indicating that respondents were more likely to choose lower cost options. On average, respondents preferred lower noise levels, an extension of prohibition of construction activity to weekends, eves, and public holidays, as well as a reduction in the duration of construction activity. Respondents also preferred construction activity to start later and end earlier.

With the exception of the prohibition of construction activity on weekends and public holidays, the random parameter logit found that respondents' preferences for non-cost attributes were heterogeneous. The standard deviations of these variables were found to be statistically different from zero at the 1% level of significance, indicating that these coefficients were distributed around the mean and that different respondents had different preferences for these attributes.

The mean of the ASC in the random parameter logit model was not statistically significant, indicating that respondents did not choose the status quo option with a higher probability. Since the ASC provides information on whether unobserved factors influenced respondents' preference for the status quo option,

Results from Table 8-12 enable the estimation of the willingness-to-pay for each attribute. The variables of the attributes are estimated from the Krinsky-Robb bootstrapping procedure. The estimated willingness-to-pay are presented in Table 8-13.

Table 8-13 Willingness-to-pay for the attributes described in Table 8-12

	Willingness-to-pay (S$)	95% Confidence interval
Reduction in noise level (per dB reduction)	7	(3, 10)
Work prohibited on weekends and public holidays	–	
Work prohibited on weekends, eves and public holidays	41	(22, 60)
Reduction in duration of construction activity (in months)	4	(3, 5)
Change in start time of construction activity (per hour later)	19	(14, 24)
Change in end time of construction activity (per hour earlier)	8	(4, 12)

Note: Statistically insignificant variables were suppressed.

The estimated willingness-to-pay of some attributes were lower as compared to the willingness-to-pay estimated from the conditional logit models. For example, the willingness-to-pay for noise abatement was S$7 per dB for a three-year duration as compared to S$17 in the conditional logit model. Further, the willingness-to-pay for extension of prohibition of construction activity to only Saturdays and public holidays was not statistically significant. The average willingness-to-pay for an extension of the prohibition of construction activity to include weekends, eves and public holidays was S$41 over a three-year duration as compared to S$75 in the conditional logit regression. Similarly, willingness-to-pay for a reduction in construction duration was S$4 per month for a three-year period in the random parameter logit, compared to S$5 in the conditional logit. However, the estimated average willingness-to-pay for start and end times were higher in the random parameter logit as compared to the conditional logit regression.

Since the random parameter logit regressions relax the assumption that the unobserved component of utility is identically and independently distributed, the random parameter logit regressions are preferred. Further, the random parameter logit regressions provide a more conservative estimate of the willingness-to-pay for construction noise abatement. Hence, if the marginal costs of construction noise abatement are sufficiently low to provide yield potential Pareto improvements with the marginal benefits estimated from the random parameter logit, they will also yield potential Pareto improvements with the conditional logit regression.

8.3.4 Diminishing marginal utility

In order to identify the effects of diminishing marginal utility, a regression was run with dummies for each noise level instead of a linear specification. Results of this regression are shown in Table 8-14. Each of these dummy variables was included as a random parameter that can vary in the population. Since the direction of respondents' preferences is not known *a priori*, these variables were defined to have a normal distribution. Similar to the random parameter logit regression conducted in Table 8-12, all other non-cost attributes were treated as normally distributed random parameters. A full set of controls was also included and 297 anomalous respondents were excluded.

Table 8-14 Random parameter logit regressions on field survey to estimate diminishing willingness-to-pay for construction noise abatement

	Random parameter logit	
	(1)	
	Mean	Standard deviation
Attributes		
Random parameters		
5dB reduction from 75dB	-0.0785	2.462***
	(0.535)	(0.228)
10dB reduction from 75dB	0.546	3.104***
	(0.899)	(0.336)
15dB reduction from 75dB	2.703***	3.683***
	(0.945)	(0.293)
20dB reduction from 75dB	2.422***	3.954***
	(0.562)	(0.336)
Work prohibited on weekends and public holidays	0.210	1.141***
	(0.213)	(0.185)
Work prohibited on weekends, eves and public holidays	0.698***	1.382***
	(0.146)	(0.175)
Reduction in duration of construction activity (in month)	0.0737***	0.0953***
	(0.0208)	(0.00963)
Change in start time of construction activity (per hour later)	0.167***	0.500***
	(0.0409)	(0.0508)
Change in end time of construction activity (per hour earlier)	0.0715**	0.481***
	(0.0338)	(0.0461)
Fixed parameters		
Cost	-0.0164***	
	(0.00403)	
Control variables		
Age	-0.00372	
	(0.00722)	
Female	-0.267	
	(0.237)	
Malay	-0.992***	
	(0.325)	
Indian	1.163***	
	(0.396)	
Other	-1.049	
	(0.656)	
Household size	0.0174	
	(0.0370)	
Income	0.228***	
	(0.0575)	
Private housing	1.281***	
	(0.393)	
Hypothesis tests (*p*-value):		
5dB reduction versus 10dB reduction	0.3522	
10dB reduction versus 15dB reduction	0.0000	
15dB reduction versus 20dB reduction	0.7141	
Log-likelihood	-3098.2	
McFadden pseudo R^2	0.299	
AIC	6250.5	
BIC	6450.2	
No. of observations	12072	
No. of respondents	503	

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.
Note: Control variables were interacted with the ASC. Control variables were treated as fixed variables. Definitions of variables are the same as those used in Table 8-1. Standard deviations are given for random parameters. All random parameters were assumed to have a normal distribution.

Results suggest that respondents exhibited diminishing marginal returns with respect to changes in the physical measure of noise (i.e., decibels). The point estimate for a 5dB and 10dB reduction in noise level was not statistically significant, possibly indicating that respondents were not willing to pay for small changes in noise reduction. By comparison, respondents were willing to pay for a 15dB reduction in noise abatement. This estimate was positive and statistically significant. It was also larger and statistically different from the coefficient on the 10dB reduction of noise. Finally, a 20dB reduction in noise levels was not statistically different from the 15dB reduction. Hence, respondents' preferences appeared to increase up to 15dB but a 20dB reduction was not preferred to a 15dB reduction.

Results from Table 8-14 was used to estimate the willingness-to-pay for noise abatement (Table 8-15). The willingness-to-pay for a 5dB and 10dB reduction in noise levels were not statistically different from zero. By comparison, the willingness-to-pay for a 15dB and 20dB reduction in noise levels were S$165 and S$148 per annum over a three-year period. The willingness-to-pay for a 15dB reduction was statistically different from the willingness-to-pay for a 10dB reduction. However, the willingness-to-pay for the 20dB reduction was not statistically different from the 15dB reduction. These results suggest that respondents' willingness-to-pay increased up to 15dB reduction but plateaued thereafter.

Table 8-15 Willingness-to-pay for a reduction in each noise level

	Willingness-to-pay (S$)	**95% Confidence interval**
5dB reduction from 75dB	–	
10dB reduction from 75dB	–	
15dB reduction from 75dB	165	(99, 217)
20dB reduction from 75dB	148	(85, 253)
Poe tests	*p*-value	
WTP(5dB reduction) versus WTP(10dB reduction)	0.2485	
WTP(10dB reduction) versus WTP(15dB reduction)	0.0002	
WTP(15dB reduction) versus WTP(20dB reduction)	0.6906	

Note: Statistically insignificant variables were suppressed.

These results may be due to respondents' lower willingness-to-pay for noise abatement if the environment is already quiet. For instance, when the abatement level of noise is 60dB (equivalent to the loudness of a conversation), respondents may not be willing to pay for a further reduction to 55dB (around the loudness in a library).

8.4 Conclusion

The analysis presented in this chapter addressed the first research question posed in Chapter 3. Data from the audio-based construction noise survey was analysed with conditional and random parameter logit regression models. Unlike previous stated preference studies examining the willingness-to-pay for noise abatement, the survey questionnaire analysed in this chapter described changes to construction noise levels with recorded construction noise. These recordings were played at different loudness, describing the noise level of each option in the choice card. This survey design sought to overcome the challenges of describing changes to noise level textually by enabling respondents to hear the noise levels, without the need to understand textual descriptions of noise levels.

Results from the conditional logit regression of the data obtained from the main field survey suggest that respondents were willing to pay an average of S$17 per annum for a one-decibel reduction in construction noise over the course of three years, which is the typical duration of construction activity in Singapore. When the IID assumptions of the conditional logit regression were relaxed with the estimation of a random parameter logit model, respondents were willing to pay S$7 per decibel reduction. The standard deviation of the latter estimate was statistically significant, indicating that respondents' preferences varied in the sample.

Willingness-to-pay for other attributes was also estimated. In line with intuition, respondents were willing to pay for an extension to the days when construction activity was prohibited, reduction in the duration of construction activity, later start times, and earlier end times. In combination with the willingness-to-pay for noise abatement, these willingness-to-pay estimates can inform the marginal benefits of future noise abatement policies in Singapore. The estimated marginal benefits, in turn, inform the cost-benefit framework presented in Chapter 2.

The results discussed in this chapter were drawn from the audio-based questionnaire. However, the effect of this innovation in the representation of noise on estimated willingness-to-pay for noise abatement is not known. Respondents to a text-based survey may have higher or lower willingness-to-pay for noise abatement as compared to audio-based survey respondents. Hence, the following chapter compares the results from the audio- and text-based surveys. The comparison informs how willingness-to-pay estimated from audio- and text-based surveys differ. Respondents' understanding of the questionnaire is explored as a channel that drives the difference in willingness-to-pay.

Chapter 9: Effect of Noise Representation on Estimated Willingness-to-pay for Construction Noise Abatement

This chapter investigates the third research question posed in Chapter 2: Does the use of audio recordings in a choice set improve respondents' understanding of the changes to the noise level? In the previous chapter, results from the analysis of the audio-based construction noise survey were presented. The audio-based survey sought to overcome the challenge of designing a readily understandable text-based survey by describing noise levels with construction noise recordings. However, it is not known, *a priori*, how stated preferences for noise abatement depend on audio- and text-based descriptions of noise.

This chapter analyses the data collected from the text-based survey described in Section 5.8 and compares the results of this analysis with the results from the audio-based survey presented in Chapter 8. Results from this chapter shed light on how willingness-to-pay obtained from the audio- and text-based surveys differ. Further, respondents' understanding of the information provided in the text-based survey is explored as a cause for the difference in estimated willingness-to-pay.

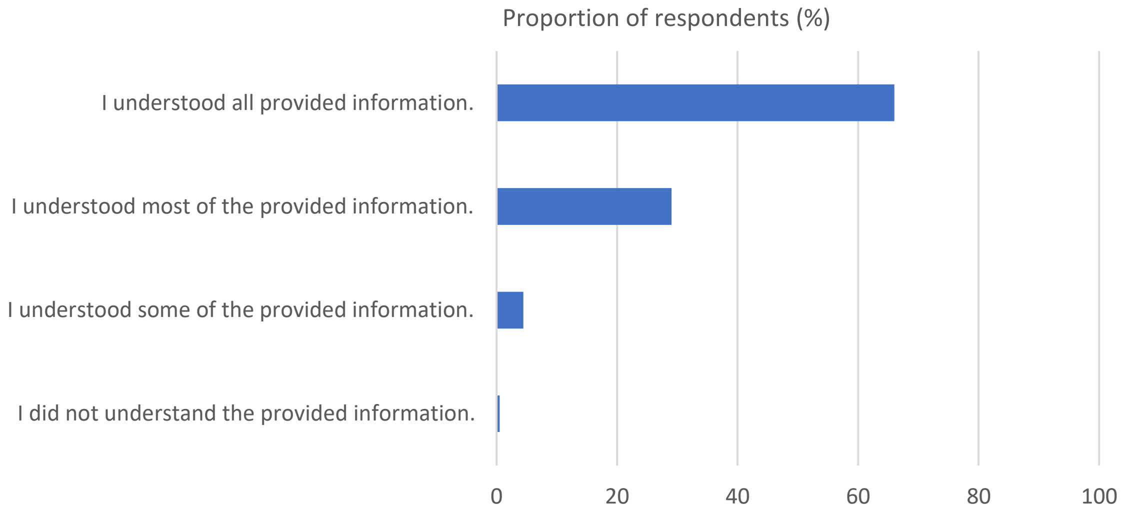
As discussed in Chapter 4, the field survey for construction noise was divided into two sub-samples, comprising of a sub-sample presented with the audio-based questionnaire and another sub-sample presented with the text-based questionnaire. Respondents to the text-based survey were asked ancillary questions to test their understanding of the presented changes. Section 9.1 presents summary statistics of these ancillary questions and discusses respondents' understanding of the information provided in the text-based survey questionnaire. Section 9.2 analyses the data from the text-based survey. Section 9.3 concludes with a discussion of the implications of the findings in this chapter on the design of stated preference surveys estimating the willingness-to-pay for noise abatement.

9.1 Respondents' understanding of the information provided in the text-based survey questionnaire

As discussed in Section 5.8, respondents to the text-based survey questionnaire made their choices on a decibel scale. Information on the decibel scale was provided to the respondent to ensure that respondents understood the decibel scale when making their choices. This information was provided before respondents stated completion of any choice set and repeated in each choice set. After respondents completed the choice sets, a series of ancillary questions was asked to ascertain respondents' understanding of the description provided in the choice sets. This section discusses respondents' answers to the ancillary questions in order to provide insights into respondents' understanding of the text-based questionnaire.

Responses to the self-reported understanding question indicate that most respondents self-reported that they understood the information provided in the survey questionnaire. Two-thirds of respondents indicated that they understood all information provided (Figure 9-1). Of the remaining third, only one respondent said that they did not understand any of the information provided.

Figure 9-1 Respondent's self-reported understanding of information provided in the choice set



In addition, a series of test questions were asked. These test questions, as well as the correct answers, are shown in Table 9-1.

Table 9-1 Test questions presented to respondents and their corresponding answers

	Correct Answer
1) The average loudness of a conversation is 60dB	True
2) Singapore's average daytime construction noise is around 75dB	True
3) A sound that is 100dB is perceived to be twice as loud as a noise that is 50dB	False
4) The decibel is measured on the logarithmic scale	True

In total, 33 respondents (or around 16% of all respondents) answered all test questions shown in Table 9-1 correctly. The breakdown of the proportion of respondents who answered each test question correctly is shown in Figure 9-2.

Figure 9-2 Proportion of respondents who answered each test question correctly

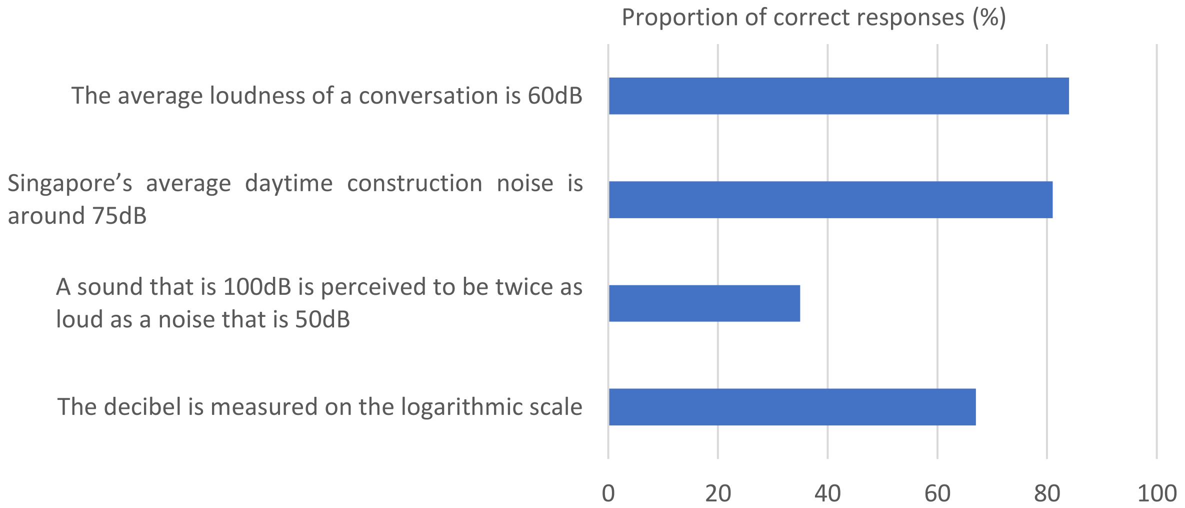


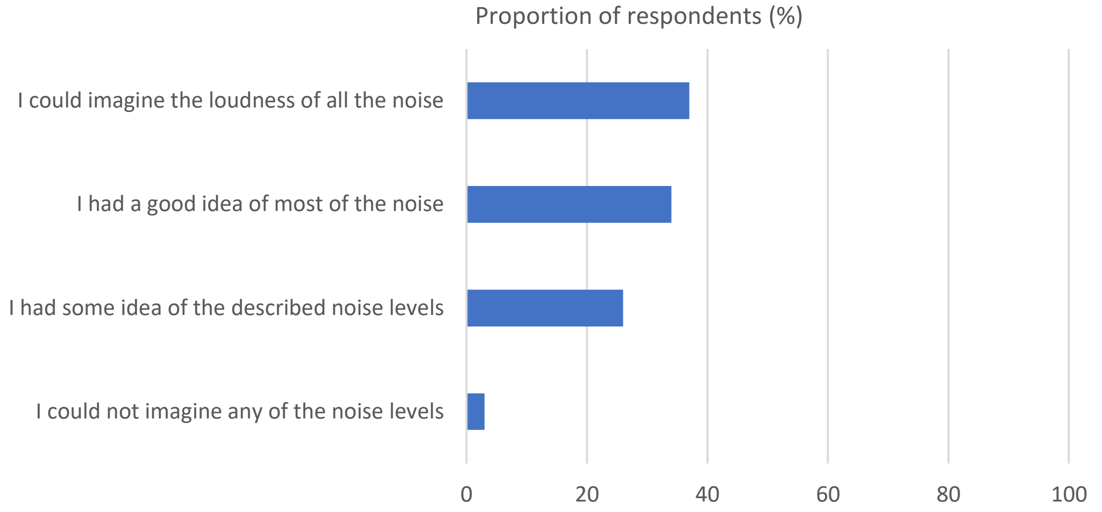
Table 9-2 provides a breakdown of respondents between their self-reported understanding and answering all test questions correctly. 72% of respondents who answered all test questions correctly indicated that they understood all provided information. By comparison, only 62% of respondents who answered at least one test question incorrectly indicated that they understood all information provided. While these summary statistics indicate that respondents who answered all test questions correctly were more likely to self-report that they understood all information in the questionnaire, only a fifth of respondents who self-reported full understanding answered all test questions correctly. Consequently, asking respondents if they understood the information provided in the questionnaire may not provide sufficient information on whether a respondent truly understood the decibel scale.

Table 9-2 Breakdown of respondent's self-reported understanding and answering all test questions correctly

	Correctly answer all test questions	
Respondent's self-reported understanding	All correct	At least one incorrect
I understood all provided information.	28	106
I understood most of the provided information.	4	55
I understood some of the provided information.	1	8
I did not understand the provided information.	0	1

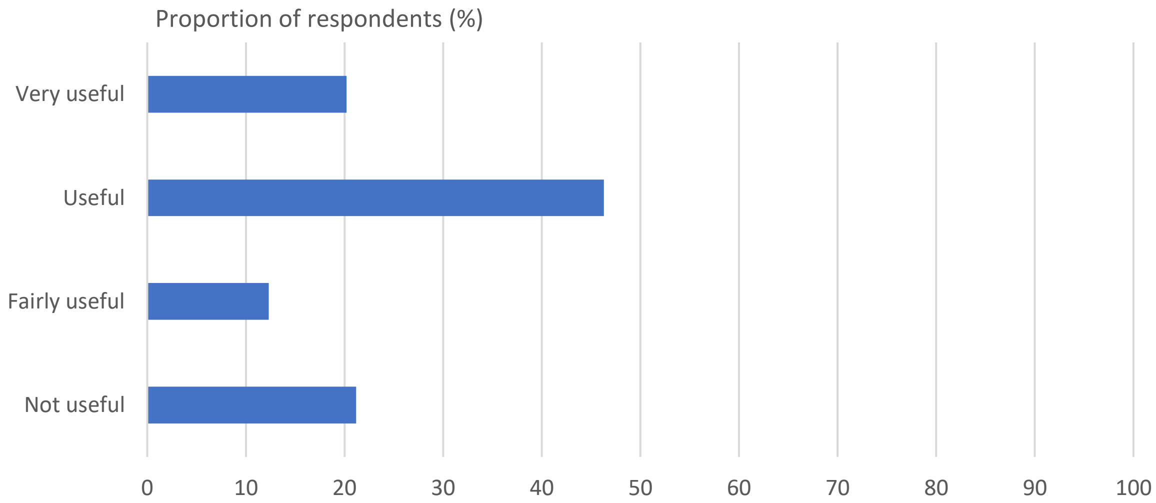
Respondents were also asked if they could imagine the sound levels corresponding to each decibel. Around a third of the respondents indicated that they could imagine all of the noise or had a good idea of most of the noise levels (Figure 9-3). However, the remaining respondents indicated that they only had some idea of the described noise levels.

Figure 9-3 Respondent's self-reported ability to imagine all noise levels



Respondents to the textual survey were also asked whether additional information could enable them to make a more informed decision. When respondents were asked whether hearing the noise recordings at different volumes instead of textual descriptions of the decibel, two-thirds of the respondents indicated that describing noise levels with recordings would be useful (Figure 9-4). These summary statistics suggest that respondents to the text-based survey preferred a survey questionnaire that described changes to noise levels with noise recordings.

Figure 9-4 Responses to whether hearing noise recordings at different volumes instead of textual descriptions of the decibel will be useful when answering the choice card



9.2 Comparison of estimated willingness-to-pay

Responses to the text-based questionnaire were analysed with conditional logit regressions. Results are presented in Table 9-3. Specification (1) repeats the results of the preferred conditional logit specification of the audio-based survey. Specification (2) to (4) presents results from the text-based survey. In Specification (2) the average willingness-to-pay for noise abatement across all respondents was estimated. Specification (3) estimates the heterogeneous willingness-to-pay among respondents who answered all test questions correctly and respondents who answered at least one test question incorrectly. Specification (4) includes a dummy variable indicating whether respondents answered each test question correctly, enabling the estimating of the effect of answering each test question correctly on the preferences for noise abatement.

Across Specifications (1) to (4), socio-economic variables were included to control for systemic taste variation. Socio-economic variables that potentially affect individuals' preferences for noise abatement include respondents' age, gender, ethnicity, household size, income, and whether the respondent lives in a private or public residence. These socio-economic variables are included in the regression by interaction with the alternative specific constant.

In order to ensure that respondents to the survey viewed the survey as consequential and interpreted the scenarios as intended, respondents who viewed the survey as inconsequential and protest respondents were excluded from the analysis. If respondents did not believe that their choices will affect noise abatement policies, they were classified as viewing the survey as being inconsequential. Protest respondents were defined to be respondents who chose the status quo for all choice sets and said that while they supported noise abatement, they should not be paying for the noise abatement policies and/or the payment will not be used effectively. Respondents who cited budgetary constraints as a reason for choosing only the status quo alternative were included in the analysis. In total 297 and 84 anomalous respondents were dropped from the audio- and text-based survey samples respectively.

Table 9-3 Conditional logit regressions on audio- and text-based survey responses

	Conditional logit			
	Audio-based survey	Text-based survey		
	(1)	(2)	(3)	(4)
Cost	-0.00410***	-0.00489***	-0.00495***	-0.00498***
	(0.000323)	(0.000922)	(0.000926)	(0.000930)
Reduction in noise level (dB)	0.0709***	0.0399***	0.0296***	-0.132***
	(0.00391)	(0.0103)	(0.0107)	(0.0288)
Answered all test questions correctly			0.0562***	
			(0.0127)	
Correctly stated that:				
The average loudness of a conversation is 60dB				0.0836***
				(0.0189)
Singapore's average daytime construction noise is 75dB				0.0681***
				(0.0153)
A 100dB sound is not twice as loud as a 50dB sound				0.00898
				(0.0108)
The decibel is measured on the logarithmic scale				0.0456***
				(0.0115)
Work prohibited on weekends and public holidays	0.197***	0.363**	0.356**	0.345*
	(0.0645)	(0.178)	(0.179)	(0.180)
Work prohibited on weekends, eves and public holidays	0.306***	0.572***	0.573***	0.577***
	(0.0666)	(0.180)	(0.181)	(0.182)
Reduction in duration of construction activity (in month)	0.0213***	0.0212***	0.0213***	0.0211***
	(0.00217)	(0.00646)	(0.00649)	(0.00651)
Change in start time of construction activity (per hour later)	0.0500***	0.0643*	0.0660*	0.0684*
	(0.0153)	(0.0383)	(0.0386)	(0.0390)
Change in end time of construction activity (per hour earlier)	0.0240*	0.0132	0.0152	0.0175
	(0.0136)	(0.0371)	(0.0373)	(0.0375)
Alternative specific constant (ASC)	-0.510***	-2.069***	-1.897***	-1.956***
	(0.171)	(0.378)	(0.384)	(0.387)
Control variables				
Age	-0.00669***	-0.0106**	-0.0119**	-0.0115**
	(0.00225)	(0.00477)	(0.00481)	(0.00499)
Female	-0.0771	-0.379**	-0.370**	-0.457***
	(0.0758)	(0.154)	(0.155)	(0.159)
Malay	-0.437***	-0.0379	0.00140	-0.0637
	(0.100)	(0.277)	(0.280)	(0.287)
Indian	0.473***	1.182***	1.169***	0.935***
	(0.130)	(0.264)	(0.269)	(0.275)
Other ethnicity	-0.277	-0.361	-0.557	-0.893*
	(0.198)	(0.477)	(0.498)	(0.488)
Household size	0.000592	0.119***	0.101**	0.131***
	(0.00866)	(0.0444)	(0.0453)	(0.0457)
Income	0.152***	0.125***	0.121***	0.115***
	(0.0195)	(0.0257)	(0.0258)	(0.0263)
Private housing	0.764***	-0.485**	-0.541***	-0.361*
	(0.141)	(0.190)	(0.191)	(0.200)
Log-likelihood	-3936.8	-757.2	-747.5	-730.9
McFadden pseudo R^2	0.109	0.276	0.285	0.301
AIC	7905.7	1546.4	1529.1	1501.8
BIC	8024.0	1641.7	1630.4	1621.0
No. of observations	12072	2856	2856	2856
No. of respondents	503	119	119	119

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: A full description of the attributes and levels is provided in Section 6.4.3.1. Control variables were interacted with the ASC. Age, Income, and Household size were continuous variables representing respondent's age, income, and household size respectively. All other control variables were dummy variables. Female was assigned a value of one if the respondent was female. The ethnicity variables, Malay, Indian, and Other, were assigned a value of one if a respondent was that particular ethnicity. Other also took a value of one if the respondent did not state their ethnicity. The base ethnicity was Chinese. Private housing took a value of one if the respondent lives in private housing. The base housing type was public housing.

In order to interpret the results, the willingness-to-pay for noise abatement was estimated. Results of these estimates are presented in Table 9-4.

Table 9-4 Comparison of estimated willingness-to-pay in audio- and text-based surveys

	Willingness-to-pay for 1dB reduction of construction noise (S$)			
	Estimates from audio-based survey	Estimates from text-based survey		
	(1)	(2)	(3)	(4)
Average	17 (15, 20)	8 (4, 13)		
(a) Did not answer all test questions correctly			6 (2, 11)	
(1) Answered all test questions wrongly				-27 (-42, -15)
	Increase in willingness-to-pay as compared to baseline			
(b) Answered all test questions correctly			11 (7, 18)	
Correctly stated that:				
(2) The average loudness of a conversation is 60dB				16 (9, 28)
(3) Singapore's average daytime construction noise is 75dB				14 (8, 22)
(4) A 100dB sound is not twice as loud as a 50dB sound				2 (-2, 6)
(5) The decibel is measured on the logarithmic scale				9 (5, 15)
	Aggregate willingness-to-pay			
(a) + (b)			17 (9, 26)	
(1) + (2)				-10 (-17, -2)
(1) + (3)				-13 (-21, -4)
(1) + (4)				-24 (-37, -12)
(1) + (5)				-17 (-27, -8)
(1) + (2) + (3)				4 (-1, 9)
(1) + (2) + (3) + (4)				6 (0, 11)
(1) + (2) + (3) + (4) + (5)				15 (9, 21)
	Other attributes			
Work prohibited on weekends and public holidays	48 (21, 75)	74 (15, 148)	72 (12, 141)	69 (10, 145)
Work prohibited on weekends, eves and public holidays	74 (49, 100)	117 (57, 193)	116 (57, 197)	115 (55, 197)
Reduction in duration of construction activity (in month)	5 (4, 6)	4 (2, 8)	4 (2, 7)	4 (2, 7)
Change in start time of construction activity (per hour later)	12 (7, 19)	13 (1, 30)	13 (0, 30)	14 (1, 29)
Change in end time of construction activity (per hour earlier)	6 (1, 12)	3 (-9, 17)	3 (-10, 17)	4 (-9, 17)

Note: 90% confidence intervals are shown in brackets. The confidence intervals were estimated with the Krinsky-Robb bootstrapping method.

To test whether the estimated willingness-to-pay obtained from the text-based survey were statistically different from the audio-based survey were tested using a procedure described in Poe, Giraud & Loomis (2005). The full combinatorial test was used to test the difference between the willingness-to-pay estimated from the audio-based survey and the aggregate willingness-to-pay for the text-based survey. The null hypothesis of the Poe test is that respondents to the audio-based survey had the same willingness-to-pay for construction noise abatement as respondents to the text-based survey. Rejection of the null indicates that the estimated willingness-to-pay from the audio- and text-based surveys were different. To implement this test, the estimates from each iteration of the bootstrap procedure was saved and the mded (measuring the difference between two empirical distributions) package in R was used to conduct the test. Results of the tests are presented in Table 9-5.

Table 9-5 Willingness-to-pay and Poe test statistics

	***p*-value of full combinatory tests**		
	(2)	(3)	(4)
Average	0.0035***		
Did not answer all test questions correctly (a)		0.0001***	
Answered all test questions correctly (a)+(b)		0.9949	
Answered all test questions wrongly (1)			0.0000***
Correctly stated that:			
The average loudness of a conversation is 60dB (1)+(2)			0.0000***
Singapore's average daytime construction noise is 75dB (1)+(3)			0.0000***
A 100dB sound is not twice as loud as a 50dB sound (1)+(4)			0.0000***
The decibel is measured on the logarithmic scale (1)+(5)			0.0000***
(1) + (2) + (3)			0.0000***
(1) + (2) + (3) + (4)			0.0001***
(1) + (2) + (3) + (4)+(5)			0.5708
	Other attributes		
Work prohibited on weekends and public holidays	0.5346	0.5626	0.6009
Work prohibited on weekends, eves and public holidays	0.3364	0.3361	0.3321
Reduction in duration of construction activity (in month)	0.6155	0.6281	0.6157
Change in start time of construction activity (per hour later)	0.9165	0.8891	0.8446
Change in end time of construction activity (per hour earlier)	0.7094	0.7491	0.7916

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: Poe tests were conducted to test whether the aggregate willingness-to-pay from the text-based survey were statistically different from willingness-to-pay from the audio-based survey.

Comparing the average willingness-to-pay obtained from the audio- and text-based survey (Specifications (1) and (2)), the willingness-to-pay obtained from the audio-based survey was higher than the text-based survey. The average willingness-to-pay were statistically different at the 1% level of significance.

The lower estimated average willingness-to-pay in the text-based survey questionnaire may have been due to respondents' lack of understanding of the decibel scale and other textual information provided in the survey questionnaire. In order to estimate the effect of respondents' understanding on willingness-to-pay, the heterogeneous effect of respondents answering test questions correctly were estimated in Specifications (3) and (4).

In Specification (3), the willingness-to-pay of respondents who answered all test questions correctly was S$11 higher as compared to respondents who answered at least one test question incorrectly. The aggregate willingness-to-pay of respondents who answered all test questions correctly was S$17. Comparing the estimated willingness-to-pay of respondents who answered all test questions correctly with the willingness-to-pay from the audio-based survey, the point estimate was not statistically different. These results suggest that respondents who completely understood the information provided in the text-based questionnaire had a similar willingness-to-pay as the audio-based survey respondents.

In Specification (4), dummy variables for correct answers to each test question were included. Respondents who answered all test questions incorrectly indicated that they had a negative and statistically significant willingness-to-pay for noise abatement. This result was counterintuitive as it suggested that respondents preferred louder construction noise. However, when the sample was restricted to the respondents who answered correctly, their incremental willingness-to-pay was positive. When respondents were able to recall that 60dB corresponded to the loudness of normal conversation and 75dB was the average loudness of construction activity, willingness-to-pay increased by S$16 and S$14 respectively. Further, when respondents had understood that the decibel scale was measured logarithmically, willingness-to-pay increased by S$9. While the willingness-to-pay among respondents who understand that a 100dB noise is not perceived as being twice as loud as a 50dB noise was positive, this estimate was not statistically significant, possibly due to the small number of respondents who answered this question correctly. These results suggest that willingness-to-pay for construction noise abatement increased if respondents have a better understanding of the information provided in the text-based questionnaire.

In both the audio- and text-based survey questionnaires, all other attributes were presented to respondents textually. The coefficients of these attributes in the regressions presented in Table 9-3 were in line with expectations. The coefficients on the cost attributes were negative, indicating that respondents preferred cheaper options. Further, the coefficients on the extension of days when construction activity are prohibited, reduction to the duration of construction activity, later start times, and earlier end times were all positive, indicating that respondents preferred these changes. No statistical difference was found between the estimated willingness-to-pay from the audio- and text-based surveys.

The regression results indicate that respondents who had a better understanding of the information provided in the survey questionnaire had a higher willingness-to-pay. Specifically, when the willingness-to-pay among respondents who answered all test questions correctly as compared to respondents who answered at least one test question incorrectly, the willingness-to-pay of the former were found to be higher as compared to the latter. Further, answering more test questions correctly led to an increase in the willingness-to-pay. In the audio-based survey, where respondents did not need to understand the textual descriptions of the decibel scale as they were able to perceive the changes to the noise levels directly, the estimated willingness-to-pay was higher than the text-based survey. Finally, the estimated willingness-to-pay for non-cost attributes that were textually described in both the audio- and text-based questionnaires were not statistically different.

Conditional logit regressions assume that the unobserved component of utility was identically and independently distributed with a Gumbel distribution. In order to relax this assumption, a random parameter logit regression was estimated. Similar to the random parameter logit regression presented in Table 8-12, all non-cost attributes were treated as random parameters. Random parameters were assumed to have a normal distribution as the direction of respondents' preferences are not known *a priori*. A full set of socio-economic controls were included. A total of 297 and 84 anomalous respondents were dropped from the audio- and text-based survey samples respectively. Results of the random parameter logit model are presented in Table 9-6.

Table 9-6 Random parameter logit regressions on audio- and text-based survey responses

	Random parameter logit			
	Audio-based survey	Text-based survey		
	(1)	(2)	(3)	(4)
Random Parameters				
Mean				
Reduction in noise level (dB)	0.0477***	-0.191***	-0.223***	-0.853***
	(0.0141)	(0.0567)	(0.0656)	(0.219)
Answered all test questions correctly			0.183**	
			(0.0879)	
Correctly stated that:				
The average loudness of a conversation is 60dB				0.316***
				(0.104)
Singapore's average daytime construction noise is 75dB				0.247**
				(0.108)
A 100dB sound is not twice as loud as a 50dB sound				0.0117
				(0.0672)
The decibel is measured on the logarithmic scale				0.188***
				(0.0703)
Work prohibited on weekends	-0.126	-0.00194	-0.0405	-0.0114
and public holidays	(0.0856)	(0.261)	(0.268)	(0.265)
Work prohibited on weekends,	0.303***	0.778***	0.780***	0.767***
eves and public holidays	(0.0909)	(0.268)	(0.268)	(0.268)
Reduction in duration of	0.0312***	0.0278***	0.0289***	0.0295***
construction activity (in month)	(0.00343)	(0.0101)	(0.0103)	(0.0103)
Change in start time of	0.139***	0.178***	0.176***	0.196***
construction activity (per hour later)	(0.0237)	(0.0638)	(0.0645)	(0.0584)
Change in end time of	0.0564***	0.0480	0.0410	0.0397
construction activity (per hour earlier)	(0.0181)	(0.0584)	(0.0600)	(0.0595)
Standard deviation				
Reduction in noise level (dB)	0.262***	0.344***	0.323***	0.214***
	(0.0157)	(0.0585)	(0.0555)	(0.0411)
Answered all test questions correctly			0.0227	
			(0.0499)	
Correctly stated that:				
The average loudness of a conversation is 60dB				0.203***
				(0.0443)
Singapore's average daytime construction noise is 75dB				0.141***
				(0.0377)
A 100dB sound is not twice as loud as a 50dB sound				0.198**
				(0.0833)
The decibel is measured on the logarithmic scale				0.112**
				(0.0490)
Work prohibited on weekends	0.0166	0.682**	0.751**	0.666**
and public holidays	(0.261)	(0.313)	(0.331)	(0.283)
Work prohibited on weekends,	0.392***	0.623*	0.648**	0.683**
eves and public holidays	(0.144)	(0.330)	(0.297)	(0.279)
Reduction in duration of	0.0379***	0.0463***	0.0501***	0.0464***
construction activity (in month)	(0.00469)	(0.0134)	(0.0137)	(0.0123)
Change in start time of	0.141***	0.137	0.160	0.00737
construction activity (per hour later)	(0.0434)	(0.114)	(0.104)	(0.163)
Change in end time of	0.121***	0.211**	0.240***	0.220***
construction activity (per hour earlier)	(0.0358)	(0.0870)	(0.0856)	(0.0745)
Fixed Parameters				
Cost	-0.00730***	-0.00844***	-0.00861***	-0.00847***
	(0.000460)	(0.00130)	(0.00132)	(0.00128)
Alternative specific constant (ASC)	0.455	-0.764	-0.717	-0.498
	(0.346)	(0.915)	(0.898)	(0.859)

Continued on next page

Control variables				
Age	0.00338	-0.00128	-0.00268	-0.000311
	(0.00509)	(0.0133)	(0.0135)	(0.0134)
Female	-0.0595	-0.516	-0.510	-0.441
	(0.165)	(0.412)	(0.414)	(0.412)
Malay	-0.408*	-0.00907	-0.0491	-0.111
	(0.228)	(0.688)	(0.728)	(0.724)
Indian	0.546**	0.816	0.694	0.478
	(0.266)	(0.684)	(0.684)	(0.637)
Other ethnicity	-0.660	0.470	0.281	-0.362
	(0.461)	(1.346)	(1.126)	(1.490)
Household size	-0.00725	-0.0477	-0.0487	-0.104
	(0.0286)	(0.119)	(0.120)	(0.115)
Income	0.0337	0.0459	0.0550	0.0392
	(0.0397)	(0.0680)	(0.0677)	(0.0657)
Private housing	0.703***	0.391	0.234	0.523
	(0.269)	(0.503)	(0.524)	(0.517)
Log-likelihood	-2983.3	-546.9	-544.2	-538.5
McFadden pseudo R^2	0.325	0.484	0.486	0.492
AIC	6010.5	1137.8	1136.3	1137.0
BIC	6173.3	1268.9	1279.3	1315.8
Hausman test statistics:				
χ^2	360.45	50.98	45.84	51.05
p--value	0.0000	0.0000	0.0002	0.0002
No. of observations	12072	2856	2856	2856
No. of respondents	503	119	119	119

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.
Note: Control variables were interacted with the ASC. Definitions of control variables are the same as those used in Table 9-3. Standard deviations are given for random parameters. All random parameters were assumed to have a normal distribution.

In comparison with the conditional logit regressions, the random parameter logit regressions provided a better fit. The McFadden pseudo R^2 were higher in the random parameter logit models, while the AIC and BIC were both lower in the random parameter logit regressions. Hausman test statistics were all statistically significant at the 1% level of significance, indicating that the coefficients in the random parameter logit regressions were different from the conditional logit models and, consequently, respondents' preferences varied in the sample. In order to interpret the results from the random parameter logit, the willingness-to-pay for noise abatement was estimated. Results of these estimates are presented in Table 9-7.

Table 9-7 Comparison of estimated willingness-to-pay in audio- and text-based surveys

	Willingness-to-pay for 1dB reduction of construction noise (S$)			
	Estimates from audio-based survey	Estimates from text-based survey		
	(1)	(2)	(3)	(4)
Average	7 (3, 9)	-22 (-37, -10)		
(a) Did not answer all test questions correctly			-26 (-44, -12)	
(1) Answered all test questions wrongly				-101 (-157, -57)
	Increase in willingness-to-pay as compared to baseline			
(b) Answered all test questions correctly			21 (4, 41)	
Correctly stated that:				
(2) The average loudness of a conversation is 60dB				37 (17, 62)
(3) Singapore's average daytime construction noise is 75dB				29 (8, 52)
(4) A 100dB sound is not twice as loud as a 50dB sound				1 (-11, 16)
(5) The decibel is measured on the logarithmic scale				22 (9, 39)
	Aggregate willingness-to-pay			
(a) + (b)			-5 (-24, 14)	
(1) + (2)				-63 (-97, -29)
(1) + (3)				-71 (-106, -38)
(1) + (4)				-99 (-147, -51)
(1) + (5)				-79 (-116, -41)
(1) + (2) + (3)				-34 (-53, 15)
(1) + (2) + (3) + (4)				-33 (-51, -13)
(1) + (2) + (3) + (4) + (5)				-10 (-23, 2)
	Other attributes			
Work prohibited on weekends and public holidays	-17 (-36, 2)	0 (-51, 52)	-5 (-58, 45)	-1 (-53, 56)
Work prohibited on weekends, eves and public holidays	41 (22, 60)	92 (42, 145)	91 (44, 153)	90 (40, 151)
Reduction in duration of construction activity (in month)	4 (3, 5)	3 (1, 6)	3 (1, 6)	3 (2, 6)
Change in start time of construction activity (per hour later)	19 (14, 24)	21 (9, 35)	20 (9, 36)	23 (13, 36)
Change in end time of construction activity (per hour earlier)	8 (4, 12)	6 (-6, 18)	5 (-7, 17)	5 (-7, 17)

Note: 90% confidence intervals are shown in brackets. The confidence intervals were estimated with the Krinsky-Robb bootstrapping method.

The Poe test was also conducted to test the difference in aggregate willingness-to-pay obtained from the text-based survey and the estimated willingness-to-pay from the audio-based survey. Results of the tests are presented in Table 9-8.

Table 9-8 Willingness-to-pay and Poe test statistics

	p-value of full combinatory tests		
	(2)	(3)	(4)
Average	0.0363**		
Did not answer all test questions correctly (a)		0.0274**	
Answered all test questions correctly (a)+(b)		0.2171	
Answered all test questions wrongly (1)			0.0315**
Correctly stated that:			
The average loudness of a conversation is 60dB (1)+(2)			0.0101**
Singapore's average daytime construction noise is 75dB (1)+(3)			0.0089***
A 100dB sound is not twice as loud as a 50dB sound (1)+(4)			0.0244**
The decibel is measured on the logarithmic scale (1)+(5)			0.0179**
(1) + (2) + (3)			0.0256**
(1) + (2) + (3) + (4)			0.0161**
(1) + (2) + (3) + (4)+(5)			0.0643*
	Other attributes		
Work prohibited on weekends and public holidays	0.6270	0.5949	0.5883
Work prohibited on weekends, eves and public holidays	0.9161	0.9673	0.9697
Reduction in duration of construction activity (in month)	0.3986	0.3843	0.2427
Change in start time of construction activity (per hour later)	0.5467	0.5758	0.6919
Change in end time of construction activity (per hour earlier)	0.3795	0.3010	0.4444

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.
Note: Poe tests were conducted to test whether the aggregate willingness-to-pay from the text-based survey were statistically different from willingness-to-pay from the audio-based survey.

Results from the random parameter logit are similar to the results from the conditional logit regressions. Respondents to the audio-based survey had a higher willingness-to-pay for noise abatement as compared to text-based survey respondents on average. This difference in willingness-to-pay was statistically significant.

Respondents to the text-based survey had higher willingness-to-pay if they answered more test questions correctly. When respondents answered all test questions correctly, no evidence was found to indicate that their willingness-to-pay was statistically different from the audio-based survey. However, when respondents answered at least one test question incorrectly, their willingness-to-pay was lower than the audio-based survey. Willingness-to-pay increased as respondents answered more test questions correctly. These results suggest that respondents with a better understanding of the survey questionnaire had a higher willingness-to-pay for noise abatement.

9.3 Conclusion

This chapter explored the difference in willingness-to-pay estimated from the audio- and text-based survey questionnaires. As discussed in Chapter 2, previous stated preference surveys estimating the marginal benefits of noise abatement used textual descriptions to illustrate changes to noise levels. However, describing noise to respondents with a readily understandable text-based survey questionnaire is challenging. Consequently, respondents may not fully understand the textual descriptions provided the survey questionnaire.

Respondents to the text-based survey were found to have a lower willingness-to-pay as compared to audio-based survey respondents. Specifically, results from the conditional logit regressions indicated that each respondent to the audio-based survey was willing to pay S$17 per annum for a one-decibel reduction over the course of three years. By comparison, the average willingness-to-pay for a one-decibel reduction estimated from the text-based survey was S$8 per annum over the course of three years. When the IID assumption of the conditional logit regression was relaxed with a random parameter logit model, the willingness-to-pay from the audio-based survey was estimated to be S$7, compared to -S$22 in the text-based survey.

These results contribute to the literature on the effect of representation methods on willingness-to-pay. Specific to noise abatement, Kaushali, Toner & Chen (2018) found that respondents' willingness-to-pay differed depending on whether linguistic or locational descriptions were used to describe noise levels. Other studies have found that respondents' willingness-to-pay for a physical good was different from textual and pictorial descriptions of the same good. For example, Bushong et al. (2010) found that respondents who were presented with a physical food item had a willingness-to-pay of 40% to 61% higher than respondents who were presented with a textual or pictorial description of the item.

This chapter also explored the effect of respondents' understanding of the information provided in the text-based survey as a potential channel driving the difference in willingness-to-pay. Results suggest that respondents with a better understanding of the text-based survey questionnaire had a higher willingness-to-pay as compared to respondents who did not fully understand the questionnaire. The upper bound of the willingness-to-pay was given by the audio-based survey. Since respondents did not need to read and understand the noise recordings, these results suggest that respondents who had a full understanding of the survey questionnaire stated the highest preferences for noise abatement.

Summary statistics of the text-based survey questionnaire indicate that a large proportion of respondents (around two-thirds of the sample) did not answer all test questions correctly. These statistics suggest that respondents to the text-based survey may not have fully understood all information provided in the survey questionnaire. If previous text-based surveys had a similarly large proportion of respondents who did not understand the survey questionnaire, the findings of this chapter suggest that previous studies may have underestimated the marginal benefits of noise abatement. Future stated preference studies estimating the willingness-to-pay for noise abatement can use an audio-based approach to provide a more accurate estimate.

In the next chapter, results from a second audio-based survey is analysed. As discussed in Chapter 4, a second survey questionnaire was designed to estimate the willingness-to-pay for road noise abatement. Results from the road noise survey provide information about the marginal benefits of road noise abatement, which can be used in the cost-benefit analysis of future policies to reduce road noise.

Chapter 10: Willingness-to-pay for Road Noise Abatement

This chapter answers the second research question: What is the willingness-to-pay for public provision of road noise abatement? Similar to the estimates of the willingness-to-pay for construction noise abatement in presented in Chapter 8, the analysis in this chapter seeks to understand the willingness-to-pay for road noise abatement. The methods presented in Chapter 4 are used to analyse the data obtained from the road noise surveys, namely the conditional logit and random parameter logit regression models.

As discussed in Chapter 4, the surveys to estimate the willingness-to-pay for road noise comprised of three phases, namely two pilot phases as well as the main field survey. Similar to the construction noise field surveys, the first pilot survey used a one-off payment to a community fund as the payment vehicle. In the second pilot survey, the payment vehicle was an annual payment to the community fund. In the main survey, an annual payment was used as the payment vehicle.

In Section 10.1, the results from the pilot survey are presented and discussed. The pilot survey informs the design of the survey questionnaire used in the main field survey. Section 10.2 presents the results from the main field survey. Marginal benefits of noise abatement are estimated from the regression results. Section 10.3 concludes with a discussion of the policy relevance of the analysis in this chapter.

10.1 Pilot field surveys

Similar to the construction noise field surveys, two pilot surveys were conducted. In the first pilot survey, respondents were presented with a one-off contribution to a community fund as the payment vehicle. The second survey used an annual contribution to a community fund as the payment vehicle. Results of both pilot surveys are presented in Table 10-1. Results of Specifications (1) and (2) refer to the first pilot survey, while Specifications (3) and (4) refer to the second pilot survey. In Specifications (1) and (3) the full sample was included in the regression. 13 anomalous respondents, defined to be protest respondents and respondents who thought the survey was inconsequential, were excluded in both Specifications (2) and (4).

Table 10-1 Conditional logit regressions on field pilot surveys to estimate the willingness-to-pay for road noise abatement

	Conditional logit			
	Pilot survey 1		Pilot survey 2	
	(1)	(2)	(3)	(4)
Cost	-0.00221***	-0.00213***	-0.00306***	-0.00331***
	(0.000606)	(0.000633)	(0.000591)	(0.000656)
Reduction in noise level (dB)	0.0449*	0.0524*	0.0362***	0.0335**
	(0.0238)	(0.0270)	(0.0119)	(0.0132)
Tighten regulations for vehicular noise emissions	-0.355	0.0414	-0.102	0.324
	(0.218)	(0.244)	(0.243)	(0.274)
Construct noise barriers along roads	0.0184	0.462	0.0566	0.546*
	(0.291)	(0.326)	(0.258)	(0.299)
Construct roads with low-noise pavement material	-0.214	0.176	-0.314	0.0817
	(0.288)	(0.328)	(0.287)	(0.325)
Retrofit homes to reduce noise	-0.596	-0.295	-0.442	0.00605
	(0.395)	(0.449)	(0.288)	(0.319)
Log-likelihood	-449.6	-337.8	-426.1	-324.6
McFadden pseudo R^2	0.035	0.039	0.068	0.053
AIC	911.1	687.7	864.1	661.3
BIC	942.0	716.9	894.9	690.3
No. of observations	1272	960	1248	936
No. of respondents	53	40	52	39

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: Attributes are described in Section 6.4.3.2. The alternative specific constants were omitted as it was collinear with the policy dummies. Specifications (1) and (3) were estimated on the full survey sample while Specifications (2) and (4) excluded protest respondents.

Comparing Specifications (1) to (2) and Specifications (3) to (4), exclusion of protest responses appeared to increase the performance of the model. Specifically, the Akaike Information Criterion (AIC) and Bayesian Information Criteria (BIC) both decreased with the exclusion of protest respondents.

Across Specifications (1) to (4) the point estimate on the cost attribute are statistically significant and negative, in line with the intuition that respondents preferred lower cost options. Further, the coefficients on the reduction of noise level were positive and statistically significant for all specifications. These results indicate that respondents preferred lower levels of road noise.

The coefficients on cost and reduction of road noise levels enable the estimation of the willingness-to-pay for noise abatement. Since the regressions excluding protest respondents provided a better estimate of the willingness-to-pay, these estimates are presented in Table 10-2.

Table 10-2 Willingness-to-pay for noise abatement for each phase of the pilot survey

	Willingness-to-pay for noise reduction (S$ per dB)	90% Confidence interval
Pilot survey 1 (excluding protest respondents)	25	(5 ,43)
Pilot survey 2 (excluding protest respondents)	10	(3, 18)

The estimates indicate that respondents' estimated willingness-to-pay for road noise reduction, when presented with a one-off payment to a community fund, was higher than when the payment was annual. Assuming that respondents in both pilot surveys had similar preferences for noise abatement, the estimated willingness-to-pay from the first pilot survey is the present value of the second survey. However, the estimated willingness-to-pay from the first and second pilot surveys were not statistically different. Poe tests between the willingness-to-pay from the two specifications had a p-value of 0.1938. Hence, the null hypothesis that the estimates from both pilot surveys are statistically significant cannot be rejected at the 10% level of significance.

These results suggest that respondents may not have accounted for the future stream of benefits from noise abatement when considering the one-off payment or may have used a high discount rate when choosing the preferred option in the choice set. In order to ensure that respondents did not need to estimate the present value of future benefits of noise abatement when making their choices, in the actual field survey the payment vehicle was an annual payment to a community fund.

In addition to the noise abatement and cost attributes, a set of policy dummies were included in the choice model. These dummies sought to understand the preference for respondents' different noise abatement measures. When protest respondents were included in Specifications (1) and (3), the coefficients on the policy dummies were all statistically insignificant, likely indicating that respondents were indifferent between different noise abatement policies. When anomalous respondents were excluded in Specification (4), respondents indicated a preference for building noise barriers along roads.

10.2 Main field survey

10.2.1 Conditional logit regressions

Following the pilot surveys, the main field survey was conducted. Data from the field survey were first analysed with conditional logit regressions. Results of these results are presented in Table 10-3. Across Specifications (1) to (3), the preferences for a linear change in noise abatement was estimated.

In Specification (1), all attributes in the choice set were included in the regression model. Costs and reduction of noise levels were included as continuous variables. Different noise abatement measures were included as dummy variables. The baseline noise abatement measure was the status quo. No alternative specific constant was included in the regression as the alternative specific constant was perfectly collinear with the policy dummies.

Specification (2) controls for the socio-economic background of the respondent. In addition to the variables included in Specification (1), Specification (2) included variables describing respondents' age, gender, ethnicity, household size, income and dwelling type was included in the regression. These variables were interacted with the alternative specific constant (ASC), which is defined to take a value of one if the option is the status quo and zero otherwise. This definition of the ASC was used as the choice sets were unlabelled.

Specification (3) is the preferred specification. In this specification, all attributes and a full set of control variables were included. 214 anomalous respondents were excluded from the regression sample. Anomalous respondents were defined to be respondents who thought the survey was inconsequential or were protest respondents. Protest respondents were defined as respondents who supported road noise abatement but did not think they should be paying for the increased noise abatement and/or did not think that their payment will be used effectively. These respondents may have rejected the policy scenario and may not have revealed their true preferences when answering the survey questionnaire.

Table 10-3 Conditional logit regressions on road noise survey responses

	Conditional logit		
	(1)	(2)	(3)
Cost	-0.00324***	-0.00330***	-0.00363***
	(0.000301)	(0.000305)	(0.000353)
Reduction in noise level (dB)	0.0486***	0.0502***	0.0682***
	(0.00579)	(0.00588)	(0.00706)
Tighten regulations for vehicular noise emissions	-0.672***	-0.270	0.210
	(0.116)	(0.202)	(0.273)
Construct noise barriers along roads	-0.951***	-0.540***	0.0222
	(0.101)	(0.194)	(0.269)
Construct roads with low-noise pavement material	-0.552***	-0.149	0.373
	(0.116)	(0.203)	(0.271)
Retrofit homes to reduce noise	-1.049***	-0.639***	-0.157
	(0.153)	(0.226)	(0.291)
Control variables			
Age		-0.0200***	-0.0111***
		(0.00223)	(0.00322)
Female		0.0102	0.111
		(0.0678)	(0.0963)
Malay		0.109	-0.222
		(0.109)	(0.147)
Indian		0.323**	0.452**
		(0.127)	(0.198)
Other		-0.727***	-0.702**
		(0.273)	(0.330)
Household size		0.0547**	0.0852***
		(0.0236)	(0.0320)
Income		0.117***	0.0765***
		(0.0148)	(0.0215)
Private housing		-0.0718	-0.174
		(0.0823)	(0.116)
Log-likelihood	-3730.5	-3619.3	-2228.5
McFadden pseudo R^2	0.151	0.176	0.113
AIC	7473.1	7266.5	4485.0
BIC	7517.4	7370.0	4580.7
No. of observations	12000	12000	6864
No. of respondents	500	500	236

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: Attributes are described in Section 6.4.3.2. Control variables were interacted with the ASC. Age, Income, and Household size were continuous variables representing respondent's age, income, and household size respectively. All other control variables were dummy variables. Female was assigned a value of one if the respondent was female. The ethnicity variables, Malay, Indian, and Other, were assigned a value of one if a respondent was that particular ethnicity. Other also took a value of one if the respondent did not state their ethnicity. The base ethnicity was Chinese. Private housing took a value of one if the respondent lives in private housing. The base housing type was public housing.

Inclusion of additional control variables improved the fit of the model. Comparing Specifications (1) and (2) of Table 10-1, the McFadden pseudo R^2 increased, while the AIC and BIC both decreased, indicating that Specification (3) provided the best fit. Further, F-tests on the joint significance of control variables were also found to be statistically significant at the 1% level of significance. The omission of protest respondents in Specification (3) led to a decrease in the AIC and BIC as compared to Specification (2). As such, exclusion of protest votes in Specification (4) provided a better fit of the data as compared to Specification (3).

Hausman tests of model equivalence between Specifications (1) and (3) against Specification (3) yielded test statistics of -48.92 and -1141 respectively. Since both test statistics are negative, a seemingly unrelated regression was estimated.

Table 10-4 Seemingly unrelated estimation tests for equality of coefficients across all specifications

	Test results			
	Specification 1 = Specification 3		Specification 2 = Specification 3	
	χ^2	*p*-value	χ^2	*p*-value
Cost	4.86	0.0274	3.81	0.0509
Reduction in noise level (dB)	22.61	0.0000	20.33	0.0000
Tighten regulations for vehicular noise emissions	12.11	0.0005	6.63	0.0100
Construct noise barriers along roads	14.87	0.0001	9.17	0.0025
Construct roads with low-noise pavement material	13.56	0.0002	8.12	0.0044
Retrofit homes to reduce noise	12.38	0.0004	6.68	0.0097

Results of the seemingly unrelated regression are shown in Table 10-4. The estimated coefficients from Specifications (1) and (2) were statistically different from Specification (3), indicating that the inclusion of control variables and the exclusion of anomalous responses influenced regression results. Given that Specification (3) controlled for systematic taste variation and excluded anomalous responses that can bias regression results, Specification (3) is the preferred specification.

In the preferred specification, the regression coefficient on the cost attribute was negative and statistically significant, indicating that respondents preferred lower-cost options. Further, the regression coefficients on the noise abatement attribute were positive and statistically significant, suggesting that respondents preferred options that resulted in lower noise levels. The coefficients on policy options were not statistically significant, suggesting that, on average, respondents were indifferent between the variable noise abatement policies.

Control variables are included in the regression by interacting the control variables with the ASC. In the preferred specification, older respondents were more likely to choose the status quo option. Ethnicities also influenced respondents' choice. Indian respondents were less likely to choose the status quo option while respondents with ethnicities other than Chinese, Malay, or Indian were more likely to choose the status quo option. Respondents with larger household sizes and higher incomes were more likely to choose options that proposed changes to the status quo.

The ratio of the costs and noise abatement attributes in Table 10-3 can be used to estimate the willingness-to-pay for noise abatement. In the preferred specification, the estimated willingness-to-pay was an annual payment of S$20 per dB reduction in road noise

(95% confidence interval: S$17 to S$24). This payment is essentially a perpetuity since respondents were asked if they are willing to pay an annual payment if a road is located near their homes. Assuming a 5% discount rate[74], the present value of an annual payment of S$20 for a one-decibel reduction in noise level was S$400.

In contrast to the willingness-to-pay for noise abatement, the estimated willingness-to-pay for different noise abatement measures were not statistically significant in the preferred specification. These results suggest that respondents were not willing to pay for these noise abatement measures on average. However, respondents may have varying preferences for these measures. The heterogeneous preferences for these measures are examined in the next section.

Recall from Section 8.3.1 that respondents were willing to pay S$17 per annum for a one-decibel reduction in construction noise over a period of three years. When the annual payment for a one-decibel reduction of construction noise was compared to road noise, the willingness-to-pay was not statistically different (*p*-value of 0.3272). However, due to the different time frames associated with construction noise and road noise, the present value of the willingness-to-pay for construction noise was S$48 per decibel reduction compared to S$400 for road noise abatement. The higher estimated present value of willingness-to-pay for road noise may be due to the permanent nature of road noise. Construction noise will end when the construction activity is completed. However, road noise affects residents permanently as it is unlikely that a road will be removed after it has been built, leading respondents to state a higher willingness-to-pay for road noise abatement.

The estimated willingness-to-pay for road noise abatement can be used to estimate the marginal benefits associated with a change in publicly-provided road noise abatement. Suppose a proposed policy reduces road noise by 5dB. Then, the marginal benefits associated with this policy is S$100 per year per resident. The marginal benefits of this policy for the whole of society can be estimated by multiplying the marginal benefits per person with the population that is adversely affected by road noise and will benefit from the policy. Assume that all working adults that are adversely affected by construction noise are willing to pay S$100 per year to implement this policy. The total resident labour force is 2.2 million (Statistics Singapore

[74] As discussed in the estimation of the present value of construction noise abatement, use of a 5% discount rate is conservative. Singapore's risk-free rate, as estimated by 2-year and 5-year Singapore Government Securities is around 1.8% (Monetary Authority of Singapore 2019a). Giglio, Maggiori & Stroebel (2015) examined Singapore's housing market and estimated that long-run discount rates was 2.6%.

2018b). Extrapolating the summary statistics from Section 7.2.2 to the whole of Singapore, 44% of the labour force experience noise from major roads or expressways. Consequently, the estimated marginal benefits of the noise abatement policy are estimated to be S$96.8 million per year.[75] Further assuming a 5% discount rate, the present value of this policy is estimated to be S$1.9 billion.

10.2.2 Random parameter logit regression

As discussed in Section 4.1.2, the conditional logit model assumes that the unobserved component of utility is independently and identically distributed (IID). In order to relax the IID assumptions, a random parameter logit regression was also estimated. In the random parameter logit regression, non-cost attributes were treated as random parameters that are normally distributed. Normal distributions were used as respondents' preferences for each variable was not known *a priori*. A full set of socio-demographic control variables were included to control for systematic taste variation. 214 anomalous respondents were excluded from the sample. These respondents were either protest respondents or thought the survey questionnaire was inconsequential.

[75] If Singapore's total labour force (which includes foreigners) was used, the annual benefits associated with this policy will be $163 million per year. In total, Singapore's labour force was 3.7 million, comprising of 2.2 million citizens and permanent residents as well as 1.5 million foreigners (Statistics Singapore 2018b). The inclusion of foreigners in computation of the aggregate marginal benefits assumes that foreigners' willingness-to-pay for noise abatement is equivalent to that of locals.

Table 10-5 Random parameter logit regressions on road noise survey responses

	Random parameter logit	
	(1)	
	Mean	Standard deviation
Random parameters (normal distribution)		
Reduction in noise level (dB)	0.0876***	0.343***
	(0.0244)	(0.0284)
Tighten regulations for vehicular noise emissions	-0.245	0.0605
	(0.648)	(0.301)
Construct noise barriers along roads	-0.219	0.640**
	(0.648)	(0.287)
Construct roads with low-noise pavement material	0.108	0.951***
	(0.648)	(0.256)
Retrofit homes to reduce noise	-0.740	1.500***
	(0.672)	(0.203)
Fixed parameters		
Cost	-0.00494***	
	(0.000484)	
Control variables, fixed		
Age	0.0156*	
	(0.00876)	
Female	0.290	
	(0.262)	
Malay	-0.721*	
	(0.408)	
Indian	0.670	
	(0.497)	
Other	-0.872	
	(0.925)	
Household size	0.0604	
	(0.0865)	
Log of income	0.170***	
	(0.0613)	
Private housing	-0.561*	
	(0.311)	
Log-likelihood	-1608.2	
McFadden pseudo R^2	0.360	
AIC	3254.4	
BIC	3384.3	
No. of observations	6864	
No. of respondents	236	

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: Control variables were interacted with the ASC. Control variables were treated as fixed variables. Definitions of variables are the same as those described in Table 10-3. Standard deviations are given for random parameters. All random parameters were assumed to have a normal distribution.

Results of the random parameter logit are shown in Table 10-5. The random parameter logit regression provided a better fit when compared to the conditional logit regression. The McFadden pseudo R^2 from the random parameter logit was higher as compared to the preferred specification from the conditional logit regression. Further, the AIC and BIC were both lower in the random parameter logit regression. When a Hausman test was conducted, the test statistic was 64.20, with a corresponding *p*-value of 0.0000, indicating that the coefficients from the random parameter logit model were statistically different from the conditional logit model. Since the random parameter logit model controlled for random heterogeneous preferences, the random parameter logit model was preferred.

The estimated coefficient on costs was negative and statistically significant. This result was in line with the intuition that respondents preferred lower cost options. Further, the coefficient on the reduction of road noise levels was positive and statistically significant, indicating that respondents preferred lower levels of road noise. The estimated willingness-to-pay for road noise abatement was an annual payment of S$18 per decibel (95% confidence interval: S$9 to S$26).

The random parameter logit regression found evidence that respondents' preferences for road noise reduction and the policies that can be implemented to reduce road noise were heterogeneous. With the exception of tightening vehicular noise emissions, the standard deviations of these variables were found to be statistically different from zero at the 1% level of significance, indicating that these coefficients were distributed around the mean and that different respondents may be different preferences for these attributes.

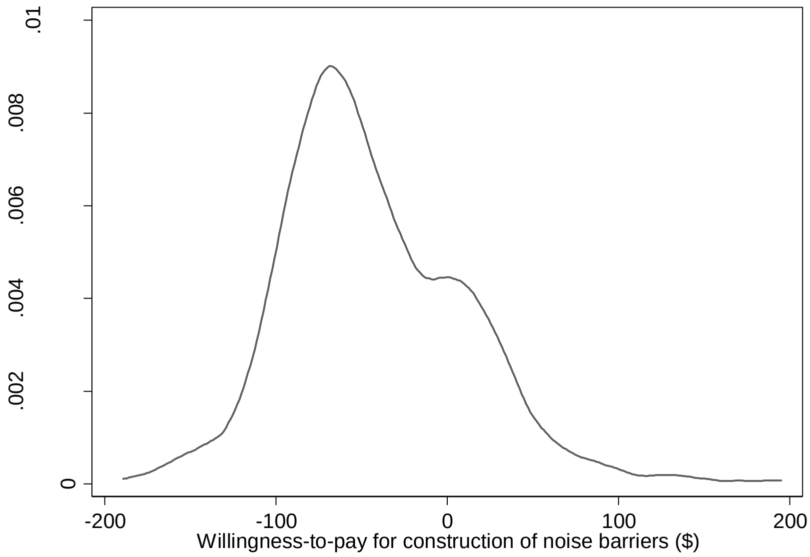
These findings provide additional information as compared to the conditional logit regressions. In particular, the estimated means of the policy variables were statistically insignificant. In the conditional logit regression, this result suggests that respondents were indifferent between the various noise abatement policies. However, in a random parameter logit model, the standard deviations on the policies to construction noise barriers, use low-noise pavement material, and retrofitting of homes were statistically significant. Consequently, the random parameter logit model suggests that the coefficient of these variables varied within the sample.

The random parameter logit regression enables estimation of individual-level willingness to pay[76]. The distribution of willingness-to-pay for the construction of road noise barriers is presented in Figure 10-1. Respondents' willingness-to-pay ranged from -S$153 to S$126. The mean and median of this distribution was -S$43 and -S$52 respectively. However, the distribution was bimodal. The first peak was at around -S$65, indicating that most respondents were not willing to pay for the construction of noise barriers. However, a second peak occurred at around S$10, indicating that some respondents preferred the construction of noise barriers. It is possible to estimate the proportion of the sample that preferred construction of noise barriers (Train 2003). The z-statistic is estimated by taking the ratio of the mean to the

[76] Individual-level willingness-to-pay was estimated with the mixlbeta command in STATA. This command used a procedure proposed by Revelt & Train (2000). See Hole (2007b) for details on the mixlbeta command.

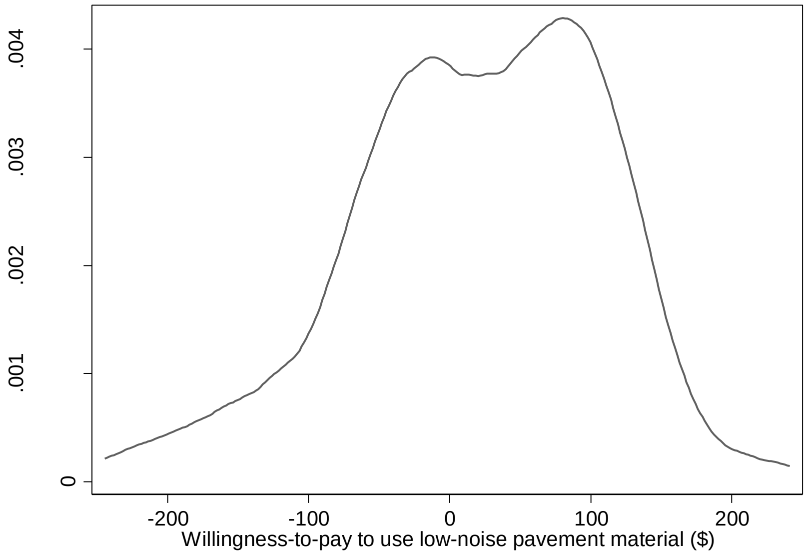
standard deviation and is estimated to be -0.342. The corresponding cumulative distribution of this *z*-statistic indicates that 36% of the sample were willing to pay for the construction of noise barriers. These results suggest that a majority of respondents were unwilling to pay for the building of noise barriers along roads, although a minority preferred this option.

Figure 10-1 Individual-level willingness-to-pay for construction of noise barriers



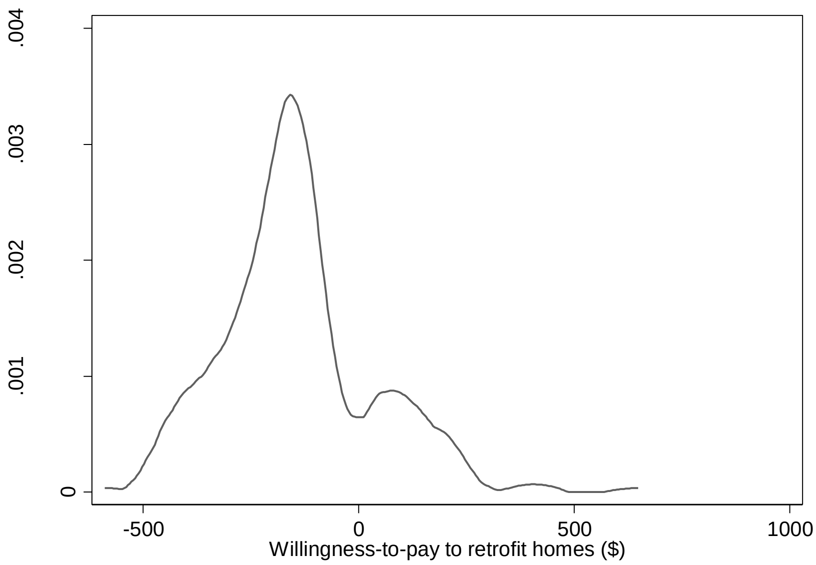
Individual-level willingness-to-pay low-noise pavement material is shown in Figure 10-2. Willingness-to-pay ranged from -S$218 to S$206, with a median and mean of S20 and S$28 respectively. This distribution was also bimodal. The first peak occurred at -S$10 and the second peak occurred at S$80. Around 55% of the respondents were willing to pay for low-noise pavement material and the remainder were unwilling to pay for this road noise abatement policy. These results suggest that a majority of respondents were willing to pay for low noise pavement material.

Figure 10-2 Individual-level willingness-to-pay to use low-noise pavement material



Finally, individual-level willingness-to-pay to retrofit homes is shown in Figure 10-3. Willingness-to-pay ranged from -S$467 to S$405. The median and mean were -S$155 and -S$146 respectively. Similar to the previous two policies, the distribution of willingness-to-pay for this policy was also bimodal. The first peak occurred at around -S$150 and the second peak occurred at around S$75. A larger proportion (68%) of the sample were unwilling to pay for retrofitting of their homes, although some respondents preferred this policy.

Figure 10-3 Individual-level willingness-to-pay to retrofit homes



10.3 Conclusion

This chapter addresses the second research question posed in Chapter 3. Data obtained from the road noise survey designed in Chapters 5 and 6 was analysed with conditional logit and random parameter logit regression models. Unlike previous stated preference surveys, the survey questionnaire used a novel survey questionnaire design that described different noise levels with recorded road noise. This survey questionnaire enabled respondents to hear the noise levels associated with each option in the choice sets. As discussed in the previous chapter, respondents to the audio-based survey likely had a better understanding of described noise levels and provide more accurate responses than text-based questionnaires.

Results presented in this chapter provide information on the willingness-to-pay for road noise abatement. The results from the conditional logit regression indicate that each respondent was willing to pay S$20 per annum for a one-decibel reduction of road noise on average. When the IID assumptions of the conditional logit regression were relaxed with a random parameter logit regression, the willingness-to-pay was estimated to be S$18 per annum for a one-decibel reduction in noise levels. The willingness-to-pay for various road noise reduction policies were also examined. Respondents' preferences for these policies were found to be heterogeneous.

The estimated willingness-to-pay for road noise abatement informs the cost-benefit analysis framework presented in Chapter 2. Specifically, conducting cost-benefit analysis of changes to road noise abatement policies require information on the marginal benefits and marginal costs of noise abatement. Results in this chapter provide information on the former. The cost-benefit analysis, in turn, sheds light on whether the proposed change to road noise policy results in a potential Pareto improvement leading to an increase in society's welfare, enabling the evaluation of future road noise abatement policies.

The next chapter completes the third part of the thesis (comprising Chapters 7 to 11). The potential sources of heterogeneous preferences for noise abatement are presented and discussed. The effect of these potential sources of heterogeneity has not been fully examined in the literature and results provide estimates of the marginal benefits of noise abatement among segments of the population.

Chapter 11: Heterogeneous Preferences for Noise Abatement

This chapter addresses Research Questions (4) to (6). Potential sources of heterogeneous preferences are examined, namely the public provision of noise abatement, hearing sensitivity, and distance between residents' homes and the nearest construction site or road. As discussed in Chapter 2, these possible sources of heterogeneity have not been fully examined in the literature. Results from this chapter inform the marginal benefits of noise abatement among segments of the populations, enabling the estimation of the marginal benefits of noise abatement among segments of the population.

The potential sources of heterogeneity are analysed in turn. Section 11.1 analyses the effect of privately-provided noise abatement on willingness-to-pay for public provision of noise abatement. The analysis in this section addresses Research Question (4). Section 11.2 investigates Research Question (5) by estimating the effect of hearing sensitivity on willingness-to-pay for public provision of noise abatement. As discussed in Section 5.9, a hearing acuity test was conducted to ascertain respondents' hearing sensitivity. Effects of respondents' measured hearing sensitivity on willingness-to-pay were analysed in this section. Section 11.3 answered Research Question (6) by analysing the effect of the distance between respondents' houses and the nearest construction site or road on their willingness-to-pay for noise abatement.

The analysis conducted in this chapter uses data from the main audio-based field surveys. In each section, results from the construction and road noise surveys are presented and discussed.

11.1 Heterogeneous effects of private investment in noise abatement

Recall from Section 2.2.2 that the aggregate noise level experienced by resident i can be described with:

$$L_{P_i} = \sigma\left(L_{P_i}^0, \varphi\left(L_{W_j}, r_{i,j}, A_{i,j}, \alpha_j\right)\right), \forall j \qquad (11\text{–}1)$$

where L_{P_i} is the sound pressure level at resident i. $L^0_{P_i}$ is the background noise level in the absence of noise from construction activity or roads. L_{w_j} is the sound power level of noise emitted by noise source j. $r_{i,j}$ and $A_{i,j}$ are the distance between noise source j and resident i as well as the absorption along the sound path respectively. $\sigma(\cdot)$ and $\varphi(\cdot)$ are the noise aggregating and noise transfer functions respectively. Finally, α_j are the noise abatement measures.

As discussed in Chapter 1 and Section 2.3.3, noise is a local pollutant that can be abated with publicly- or privately-provided measures. Publicly-provided noise abatement measures are mandated by the government to reduce the impact of noise from construction sites or roads. Examples include limits to the sound pressure level experienced by residents and mandating that noise sources implement certain noise abatement measures. Residents also have the option to privately invest in noise abatement measures. Private noise abatement measures include the installation of soundproof windows, turning on the air-conditioning when windows are closed and the use of headphones to reduce the impact of construction noise. Investment into these measures can reduce the sound pressure level within the resident's homes.

Hence, Equation (11-1) can be re-written to include the privately- and publicly-provided abatement measures:

$$L_{P_i} = \alpha_i^{pvt} \sigma\left(L^0_{P_i}, \varphi\left(L_{w_j}, r_{i,j}, A_{i,j}, \alpha_j^{pub}\right)\right), \forall j \qquad (11\text{–}2)$$

where α_i^{pvt} refers to the privately-provided abatement measures and α_j^{pub} refers to publicly-provided abatement measures.

In Equation (11-2), α_j^{pub} is an argument in the transfer function of construction site j as publicly mandated noise abatement measures are site-specific. By contrast, since private noise abatement measures are implemented to reduce noise within respondents' property, all sources of construction noise are reduced by an equal amount. As such, α_i^{pvt} is the reduction in sound pressure levels as a result of private abatement measures.

Specific to changes in ambient noise level, the marginal benefits associated with a unit change in noise levels due to publicly-provided noise abatement policy conditioned on a given level of privately-provided noise abatement is:

$$MB_i\left(\Delta L_{P_{ik}}\left(\alpha_{jk}^{pub}\right)\right)\Big|_{\alpha_i^{pvt}} = \frac{\Delta price_{ik}}{\Delta\left(\Delta L_{P_{ik}}\left(\alpha_{jk}^{pub}\right)\right)}\Bigg|_{\alpha_i^{pvt}} = -\frac{\partial u_{ik}/\partial \Delta L_{P_{ik}}\left(\alpha_{jk}^{pub}\right)}{\partial u_{ik}/\partial price_{ik}}\Bigg|_{\alpha_i^{pvt}} \tag{11-3}$$

In the absence of privately-provided noise abatement, the marginal benefits associated with publicly-provided noise abatement will likely be positive. Noise pollution causes harm to residents who are likely willing to pay for reductions in noise levels if there were no other recourse to reduce noise. However, residents can privately invest in noise abatement measures within their homes. Consequently, the marginal benefits of public abatement when residents have the option to invest privately in noise abatement is unclear.

Prior private provision of noise abatement substitutes publicly-provided noise abatement. However, the effect of prior investment in noise abatement on the willingness-to-pay for publicly provided noise abatement is unclear. On the one hand, privately-provided noise abatement may be sufficiently effective that respondents are less willing to pay for public provision of noise abatement.

On the other hand, residents that are more annoyed by noise pollution are more likely to implement private noise abatement measures. Consequently, prior spending on privately provided noise abatement measures may indicate that the resident is more annoyed by noise. These residents may still be willing to pay for public provision of noise abatement even though they have previously

Consequently, the relationship between private- and public-provision of noise abatement is ambiguous. Empirical analysis of the data collected in the surveys can provide information on this relationship. Results of the analysis can, in turn, provide information on the design of future noise abatement policies.

While it may be desirable to estimate the willingness-to-pay for publicly-provided noise abatement conditioned on each decibel decrease in noise level from privately-provided measures, data on privately-provided noise abatement was not collected as this will require noise measurement both before and after noise abatement has been privately provided. These measurements may be intrusive as they take place at the respondents' homes. Further, measuring noise levels require the purchase of costly audiometers. In place of physical reduction in noise levels, self-reported expenditure on noise abatement was used to proxy for privately-provided noise abatement, since residents who have higher expenditure on privately-provided noise abatement likely have a greater reduction in noise levels. While the proxy may be imperfect as respondents may not be able to estimate the present value of all costs of noise abatement (e.g., the additional costs of air conditioning), the proxy overcomes the practical challenge of measuring noise at respondents' homes.

In this section, the possible heterogeneous effect of privately-provided noise abatement on willingness-to-pay for construction and road noise abatement is estimated in turn.

11.1.1 Effect on willingness-to-pay for construction noise abatement

To estimate the effect of privately-provided noise abatement on the willingness-to-pay for publicly-provided construction noise abatement, conditional logit and random parameter logit regressions were estimated. The regressions were estimated on the main audio-based field survey sample. In the regression, all attributes in the construction noise choice model were included. Respondents' self-reported private expenditure on noise abatement measures interacted with the noise abatement attribute. This specification estimates the change in willingness-to-pay for publicly-provided noise abatement as expenditure on privately-provided noise abatement changes.

A full set of socio-economic variables was included to control for systematic taste variation. These variables include respondents' age, gender, ethnicity, household size, income, and dwelling type. These variables are the same as those included in the preferred models to estimate the willingness-to-pay for construction and road noise. In addition to the attributes, an alternative specific constant was included in both the regressions. As the construction noise survey was unlabelled, the alternative specific constant took a value of one for the status quo alternative and zero otherwise.

In both regressions, 297 anomalous respondents were excluded. Anomalous respondents were defined to be protest respondents and respondents who did not view the survey as being consequential. Protest respondents universally chose the status quo option and supported the implementation of publicly-provided construction noise abatement measure but thought that they should not be paying for these measures and/or that their payment will not be used effectively. These respondents were excluded as they rejected the scenario in the choice set and may not have revealed their true preferences.

In the random parameter logit regression, non-cost attributes were treated as normally distributed random parameters. These attributes were assumed to be normally distributed as respondents' direction of preference for these attributes were not known *a priori*. The cost attribute was treated as a log-normally distributed random parameter. Respondents should universally prefer lower cost options and the coefficient on the cost attribute will likely be negative (Train 2003).

Table 11-1 Heterogeneous effect of privately-provided noise abatement on willingness-to-pay for publicly-provided construction noise abatement

	Conditional logit	Random parameter logit	
	(1)	(2)	
	Coefficient	Mean	Standard deviation
Cost	-0.00410***	-4.930***	2.842***
	(0.000321)	(0.185)	(0.210)
Reduction in noise level (dB)	0.0712***	0.115***	0.101***
	(0.00402)	(0.00841)	(0.00933)
Log of private investment into noise	-0.000552	-0.00990**	0.0110
abatement measures	(0.00150)	(0.00494)	(0.0120)
Work prohibited on weekends	0.197***	-0.0214	0.0211
and public holidays	(0.0655)	(0.0836)	(0.238)
Work prohibited on weekends,	0.306***	0.193**	0.0736
eves and public holidays	(0.0680)	(0.0865)	(0.295)
Reduction in duration of	0.0213***	0.0291***	0.0334***
construction activity (in month)	(0.00222)	(0.00331)	(0.00484)
Change in start time of	0.0499***	0.0909***	0.0369
construction activity (per hour later)	(0.0154)	(0.0212)	(0.0802)
Change in end time of	0.0240*	0.0444***	0.0301
construction activity (per hour earlier)	(0.0135)	(0.0165)	(0.0672)
Alternative specific constant (ASC)	-0.507***	1.723***	
	(0.177)	(0.473)	
Control variables			
Age	-0.00676***	0.0125*	
	(0.00230)	(0.00760)	
Female	-0.0777	-0.264	
	(0.0751)	(0.259)	
Malay	-0.437***	0.495	
	(0.0986)	(0.411)	
Indian	0.470***	0.733*	
	(0.131)	(0.417)	
Other	-0.279	-1.339**	
	(0.202)	(0.603)	
Household size	0.000600	-0.0273	
	(0.0123)	(0.0300)	
Log of income	0.152***	-0.0232	
	(0.0202)	(0.0571)	
Private housing	0.764***	0.148	
	(0.142)	(0.357)	
Log-likelihood	-3936.8	-2627.2	
McFadden pseudo R^2	0.109	0.405	
AIC	7907.5	5304.4	
BIC	8033.3	5489.3	
No. of observations	12072	12072	
No. of respondents	503	503	

* p<0.1, ** p<0.5, *** p<0.01, standard errors are shown in brackets.

Note: Attributes are described in Section 6.4.3.1. The log of private investment into noise abatement measures was interacted with the noise abatement variable. Control variables were interacted with the ASC. Age, Income, and Household size were continuous variables representing respondent's age, income, and household size respectively. All other control variables were dummy variables. Female was assigned a value of one if the respondent was female. The ethnicity variables, Malay, Indian, and Other, were assigned a value of one if a respondent was that particular ethnicity. Other also took a value of one if the respondent did not state their ethnicity. The base ethnicity was Chinese. Private housing took a value of one if the respondent lives in private housing. The base housing type was public housing. Standard deviations are given for random parameters. All non-cost attributes were assumed to have a normal distribution. The cost attribute was assumed to follow a log-normal distribution.

Results of these regressions are presented in Table 11-1. Comparing the conditional logit regression and the random parameter logit regression, the random parameter logit regression provided a better fit of the data. The McFadden pseudo R^2 was higher in the random parameter logit as compared to the conditional logit regression. Further, the AIC and BIC were both lower in the random parameter logit. When a Hausman test was conducted, the test statistic was 519.46, with a corresponding p-value of 0.0000. Hence, the random parameter logit is preferred to the conditional logit.

In the conditional logit regression, the coefficient on privately-provided noise abatement was not statistically significant, suggesting that prior private expenditure on abatement measures did not affect willingness-to-pay for publicly-provided noise abatement. However, results of the random parameter logit regression indicate that privately-provided noise abatement substituted publicly-provided noise abatement. Increased private expenditure on noise abatement led to a lower preference for noise abatement.

The substitutability between private and public provision of noise abatement supports the hypothesis that respondents seek to avert noise pollution by privately-providing defensive measures. Since respondents that have invested in private measures experience lower levels of noise, their willingness-to-pay for public provision of noise abatement may also be lower.

Results from the random parameter logit regression can be used to estimate the willingness-to-pay for publicly-provided noise abatement conditioned on prior private expenditure on noise abatement. The results indicate that a 100% increase in private investment for noise abatement is associated with a decreased willingness-to-pay for publicly-provided noise abatement of S$1.4 per dB each year for three years. The corresponding 90% confidence interval is -S$2.6 to -S$0.2, suggesting that the estimated willingness-to-pay is statistically different from zero at the 10% level of significance.

11.1.2 Effect on willingness-to-pay for road noise abatement

Conditional logit and random parameter logit regressions were estimated to estimate the effect of prior private expenditure on noise abatement on the willingness-to-pay for publicly-provided road noise abatement. Both regressions were estimated on the main field survey. Similar to the specification for construction noise reduction, respondents' self-reported private expenditure on noise abatement measures was interacted with the noise abatement attribute. In both regressions, all attributes and a full set of socio-economic control variables were included. 214 respondents were excluded as they either were protest respondents or did not believe that the survey was consequential.

In the random parameter logit regression, non-cost attributes were treated as normally distributed random parameters. These attributes were assumed to be normally distributed as respondents' direction of preference for these attributes were not known *a priori*. The cost attribute was treated as a log-normally distributed random parameter. Respondents should universally prefer lower cost options and the coefficient on the cost attribute will likely be negative.

Table 11-2 Heterogeneous effects of privately-provided noise abatement on willingness-to-pay for publicly-provided road noise abatement

	Conditional logit	Random parameter logit	
	(1)	(2)	
	Coefficient	Mean	Standard deviation
Cost	-0.00363***	-4.885***	2.289***
	(0.000353)	(0.139)	(0.212)
Reduction in noise level (dB)	0.0638***	0.141***	0.120***
	(0.00718)	(0.0148)	(0.0129)
Log of private investment into noise	0.00605***	0.0108**	0.0131**
abatement measures	(0.00180)	(0.00545)	(0.00562)
Tighten regulations for vehicular noise	0.215	-0.218	0.0773
emissions	(0.273)	(0.817)	(0.196)
Construct noise barriers along roads	0.0283	-0.318	0.437
	(0.269)	(0.817)	(0.267)
Construct roads with low-noise	0.381	0.256	0.821***
pavement material	(0.271)	(0.817)	(0.252)
Retrofit homes to reduce noise	-0.149	-0.494	0.948***
	(0.291)	(0.831)	(0.193)
Control variables			
Age	-0.0109***	0.0276***	
	(0.00322)	(0.0105)	
Female	0.136	0.895***	
	(0.0966)	(0.333)	
Malay	-0.165	-0.922*	
	(0.148)	(0.489)	
Indian	0.465**	0.0828	
	(0.198)	(0.539)	
Other	-0.652**	-0.619	
	(0.330)	(1.044)	
Household size	0.0790**	0.00179	
	(0.0320)	(0.116)	
Log of income	0.0712***	0.481***	
	(0.0216)	(0.0986)	
Private housing	-0.147	-0.898**	
	(0.117)	(0.390)	
Log-likelihood	-2222.5	-1495.4	
McFadden pseudo R^2	0.116	0.405	
AIC	4475.0	3034.7	
BIC	4577.5	3185.1	
No. of observations	6864	6864	
No. of respondents	286	286	

* p<0.1, ** p<0.5, *** p<0.01, robust standard errors are shown in brackets.

Note: Attributes are described in Section 6.4.3.2. The log of private investment into noise abatement measures was interacted with the noise abatement variable. Control variables were interacted with the ASC. See Table 11-1 for a description of control variables. Standard deviations are given for random parameters. All non-cost attributes were assumed to have a normal distribution. The cost attribute was assumed to follow a log-normal distribution.

Table 11-2 presents the results from the road noise survey. Comparing the statistics from the conditional logit regression and the random parameter logit regression, the random parameter logit regression appeared to provide a better fit of the data. The McFadden pseudo R^2 was higher in the random parameter logit regression, with the AIC and BIC were both lower.

Further, the Hausman test statistic was 181.20, with a corresponding *p*-value of 0.0000. The results suggest that the coefficients in the random parameter logit were statistically different from the conditional logit regression.

The coefficient on privately-provided noise abatement was negative and statistically significant in both regressions. This result indicates that respondents were more willing to pay for noise reduction when they have already privately invested in noise abatement measures. In comparison with the results from the construction noise survey, private provision of road noise abatement measures was associated with increased willingness-to-pay for public provision of road noise abatement.

Several reasons account for the positive relationship between prior provision of noise abatement and willingness-to-pay for publicly provided noise abatement. First, private noise abatement measures may not be effective in reducing road noise to a level that eliminates respondents' annoyance with road noise. Since road noise is permanent, annoyance with road noise likely has a larger adverse effect on respondents as compared to disamenities due to construction noise. Consequently, respondents who have invested in road noise abatement are still willing to pay for additional public provision of noise abatement. Second, respondents who place higher values on a quieter environment may have selectively invested in road noise abatement measures privately. Hence, these respondents will also be willing to pay more for publicly provided noise abatement.

Results of the analysis can be used to estimate the willingness-to-pay for publicly-provided road noise abatement conditioned on prior private spending for noise abatement. Based on the regression estimates from the conditional logit regression, a 100% increase in private investment for noise abatement is associated with an increase of S$1.6 per dB in willingness-to-pay for publicly-provided noise abatement (90% confidence interval: S$0.6 to S$2.7). Results from the random parameter logit regression suggest that willingness-to-pay increased by S$1.4 per dB when private spending increased by 100% (90% confidence interval: S$0.2 to S$2.7).

11.2 Heterogeneous effects of hearing sensitivity

Hearing sensitivity may also affect an individual's willingness-to-pay for noise abatement. As discussed in Section 2.3.3, individuals' physiological condition may affect their willingness-to-pay for measures to protect their health. For example, studies in health economics found that individuals' willingness-to-pay to reduce the risks of suffering a targeted disease increases with the severity of a comorbidity condition (Fujii & Osaki 2019; Liu 2004).

In a similar vein, an individuals' willingness-to-pay for noise abatement may depend on the individuals' hearing sensitivity. The effect of hearing sensitivity on willingness-to-pay for noise abatement is ambiguous. On the one hand, increased hearing sensitivity may cause individuals to be more willing to pay for noise abatement as they are more annoyed by construction or road noise. On the other hand, individuals with insensitive hearing may be aware that they need to protect their hearing to prevent further deterioration. Consequently, individuals with lower hearing sensitivity may be more willing to pay for noise abatement.

As discussed in Section 5.9.2, a hearing acuity test was included in the survey. Previous stated preference surveys estimating the willingness-to-pay for noise abatement have not included tests to estimate a respondent's hearing sensitivity as they used textual descriptions instead of playing noise to respondents. The hearing acuity test included in the survey questionnaire seeks to estimate the quietest sound perceivable by the respondent. An individual with more sensitive hearing will likely be able to perceive quieter sounds and vice versa.

11.2.1 Effect on willingness-to-pay for construction noise abatement

The effect of hearing sensitivity on respondents' preferences for construction noise abatement was analysed with conditional logit and random parameter logit regressions. In both specifications, the quietest perceivable test tone as measured by the hearing acuity test was interacted with the noise abatement variable.

Both specifications included a full set of socio-economic variables to control for systematic taste variation. Further, 297 respondents were excluded from the sample as they were protest respondents or thought the survey was inconsequential. In the random parameter logit regression, non-cost attributes were assumed to have a normal distribution as the direction of respondents' preferences are not known *a priori*. The cost attribute was assumed to follow a log-normal distribute as respondents likely prefer lower cost option as compared to more expensive options.

Table 11-3 Heterogeneous effects of hearing acuity on willingness-to-pay for construction noise abatement

	Conditional logit	Random parameter logit	
	(1)	(2)	
	Coefficient	Mean	Standard deviation
Cost	-0.00421***	-4.927***	2.748***
	(0.000302)	(0.166)	(0.210)
Reduction in noise level (dB)	0.0872***	0.193***	0.0918***
	(0.0116)	(0.0436)	(0.0165)
Quietest perceivable test tone (dB)	-0.000687**	-0.00252*	-0.00164*
	(0.000342)	(0.00131)	(0.000839)
Work prohibited on weekends	0.252***	-0.0227	0.0543
and public holidays	(0.0605)	(0.0842)	(0.224)
Work prohibited on weekends,	0.358***	0.194**	-0.177
eves and public holidays	(0.0625)	(0.0874)	(0.201)
Reduction in duration of	0.0213***	0.0296***	0.0345***
construction activity (in month)	(0.00210)	(0.00338)	(0.00488)
Change in start time of	0.0392***	0.0923***	-0.0287
construction activity (per hour later)	(0.0139)	(0.0214)	(0.0920)
Change in end time of	0.0137	0.0447***	-0.0410
construction activity (per hour earlier)	(0.0126)	(0.0166)	(0.0586)
Alternative specific constant (ASC)	-0.770***	1.666***	
	(0.157)	(0.471)	
Control variables			
Age	-0.00696***	0.0138*	
	(0.00200)	(0.00756)	
Female	0.102	-0.212	
	(0.0623)	(0.260)	
Malay	-0.273***	0.551	
	(0.0881)	(0.414)	
Indian	0.631***	0.761*	
	(0.112)	(0.414)	
Other	-0.234	-1.419**	
	(0.168)	(0.552)	
Household size	0.0198	-0.0284	
	(0.0130)	(0.0301)	
Log of income	0.0580***	-0.0337	
	(0.0145)	(0.0547)	
Private housing	0.410***	0.151	
	(0.0996)	(0.355)	
Log-likelihood	-3927.8	-2626.9	
McFadden pseudo R^2	0.112	0.406	
AIC	7889.6	5303.8	
BIC	8015.4	5488.8	
No. of observations	12072	12072	
No. of respondents	503	503	

* p<0.1, ** p<0.5, *** p<0.01, robust standard errors are shown in brackets.

Note: Quietest perceivable test tone was interacted with the noise abatement variable. Control variables were interacted with the ASC. See Table 11-1 for a description of other variables. Standard deviations are given for random parameters. All non-cost attributes were assumed to have a normal distribution. The cost attribute was assumed to follow a log-normal distribution.

The results of the regression are presented in Table 11-3. The random parameter logit regression appeared to provide a better of the data as compared to the conditional logit regression. The McFadden pseudo R^2 was higher in the random parameter logit while the AIC and BIC were both lower. When a Hausman test was conducted, the test statistic was 502.34, with a corresponding *p*-value of 0.0000, indicating that the coefficients from the random parameter logit were statistically different from the conditional logit regression.

The regression coefficient on the quietest perceivable test tone is negative in both regressions, indicating that increased hearing sensitivity was associated with an increase in the willingness-to-pay for noise abatement. The quietest perceivable noise obtained from the hearing acuity test is inversely related to the individuals' hearing sensitivity since individuals who possessed more sensitive hearing will be able to perceive quieter sounds. Results from the conditional logit regression indicate that a 1dB increase in threshold perceivable noise was associated with a S$0.4 per dB reduction in willingness-to-pay for noise abatement (90% confidence interval: -S$0.6 to -S$0.3). Similarly, the estimated change in willingness-to-pay from the random parameter logit was S$0.3 per dB when threshold perceivable noise increased by 1dB (90% confidence interval: -S$0.7 to -S$0.04).

11.2.2 Effect on willingness-to-pay for road noise abatement

The main field survey for road noise abatement was analysed to estimate the effect of hearing sensitivity on willingness-to-pay for road noise abatement. Conditional and random parameter logit regressions were estimated. In both regressions, the quietest perceivable noise obtained from the hearing acuity test was interacted with the noise abatement attribute. Both regressions included a full set of socio-economic variables and 214 respondents who protested the survey or did not believe that the survey was consequential were excluded from the sample. In the random parameter logit regression, non-cost attributes were treated as normally distributed random parameters. The cost attribute was treated as a log-normally distributed random parameter.

Table 11-4 Heterogeneous effects of hearing acuity on willingness-to-pay for road noise abatement

	Conditional logit	Random parameter logit	
	(1)	(2)	
	Coefficient	Mean	Standard deviation
Cost	-0.00363***	-4.905***	2.115***
	(0.000354)	(0.166)	(0.212)
Reduction in noise level (dB)	0.148***	0.286***	-0.0719
	(0.0205)	(0.0805)	(0.0492)
Quietest perceivable test tone (dB)	-0.00247***	-0.00416*	-0.00363***
	(0.000597)	(0.00250)	(0.000857)
Tighten regulations for vehicular noise emissions	0.117	0.0569	-0.0142
	(0.275)	(0.881)	(0.253)
Construct noise barriers along roads	-0.0697	-0.0412	-0.463
	(0.270)	(0.881)	(0.366)
Construct roads with low-noise pavement material	0.285	0.516	0.889***
	(0.273)	(0.881)	(0.302)
Retrofit homes to reduce noise	-0.247	-0.250	1.164***
	(0.292)	(0.896)	(0.218)
Control variables			
Age	-0.00883***	0.0269**	
	(0.00327)	(0.0116)	
Female	0.116	0.643*	
	(0.0967)	(0.362)	
Malay	-0.197	-0.745	
	(0.147)	(0.549)	
Indian	0.469**	0.142	
	(0.199)	(0.615)	
Other	-0.773**	0.561	
	(0.332)	(2.009)	
Household size	0.0837***	-0.0262	
	(0.0320)	(0.120)	
Log of income	0.0765***	0.433***	
	(0.0216)	(0.107)	
Private housing	-0.201*	-0.660	
	(0.117)	(0.424)	
Log-likelihood	-2219.9	-1497.4	
McFadden pseudo R^2	0.117	0.404	
AIC	4469.8	3038.8	
BIC	4572.3	3189.1	
No. of observations	6864	6864	
No. of respondents	286	286	

* p<0.1, ** p<0.5, *** p<0.01, robust standard errors are shown in brackets.
Note: Quietest perceivable test tone was interacted with the noise abatement variable. Control variables were interacted with the ASC. See Table 11-2 for a description of other variables. Standard deviations are given for random parameters. All non-cost attributes were assumed to have a normal distribution. The cost attribute was assumed to follow a log-normal distribution.

Comparing the conditional logit and random parameter logit regressions, the random parameter logit regression appeared to provide a better fit of the data. The McFadden pseudo R^2 was 0.4 in the random parameter logit regression, which is higher than the conditional logit regression. Further, the AIC and BIC were both lower in the random parameter logit regression. When a Hausman test was conducted, the Hausman test statistic was 181.93 (*p*-value: 0.0000), indicating that coefficients in from the two regressions were statistically different.

The results for the road noise survey mirrored those from the construction noise survey. Respondents who had lower hearing sensitivity were less willing to pay for road noise abatement as compared to respondents with more sensitive hearing. Results from the conditional logit regression indicate that willingness-to-pay for road noise abatement decreased by S$0.7 per dB for a one-decibel increase in threshold perceivable noise (90% confidence interval: -S$1.0 to -S$0.3). Similarly, results from random parameter logit suggest that respondents were willing to pay S$0.6 per dB less when threshold perceivable noise increased by one-decibel (90% confidence interval: -S$1.1 to S$0).

11.3 Heterogeneous effects of distance to the nearest noise source

The final source of heterogeneous preferences considered in this study was the distance to the nearest noise source. The distance to the nearest noise source was used as a proxy for the level of noise due to construction activity or roads.[77] As discussed in Section 2.5.2, the sound pressure level decreases as the distance between the noise source and receptor increases. Consequently, respondents who lived nearer to construction sites may experience more disamenities from noise pollution as compared to respondents who lived further away.

11.3.1 Effect on willingness-to-pay for construction noise abatement

The heterogeneous effect of distance to the nearest construction site was estimated with conditional logit and random parameter logit regressions. The distance to the nearest construction site proxies for the level of construction noise experienced by a respondent. The distance was interacted with the noise abatement attribute. In both specifications, a full set of socio-economic control variables were included. 297 respondents were excluded as they were either protest respondents or thought that the survey was inconsequential.

[77] Ideally, the measured noise level at respondents' home should be used to as the measure of ambient noise level. However, it was not practicable to measure noise levels at each respondents' home as this measurement required purchase of decibel meters that were costly. An alternative may be noise maps that described the average noise level at respondents' homes. However, these noise maps were not available in Singapore.

Table 11-5 Heterogeneous effects of distance to nearest construction site willingness-to-pay for construction noise abatement

	Conditional logit	Random parameter logit	
	(1)	(2)	
	Coefficient	Mean	Standard deviation
Cost	-0.00411***	-4.931***	2.790***
	(0.000322)	(0.175)	(0.190)
Reduction in noise level (dB)	0.0785***	0.104***	0.105***
	(0.00445)	(0.0102)	(0.00862)
Distance to nearest construction site (m)	-0.0000957***	0.0000752	0.0000989
	(0.0000256)	(0.0000859)	(0.000177)
Work prohibited on weekends and public holidays	0.196***	-0.0206	-0.0272
	(0.0655)	(0.0835)	(0.249)
Work prohibited on weekends, eves and public holidays	0.306***	0.192**	0.0455
	(0.0681)	(0.0864)	(0.340)
Reduction in duration of construction activity (in month)	0.0213***	0.0293***	-0.0333***
	(0.00222)	(0.00331)	(0.00475)
Change in start time of construction activity (per hour later)	0.0501***	0.0906***	-0.00810
	(0.0155)	(0.0211)	(0.125)
Change in end time of construction activity (per hour earlier)	0.0241*	0.0445***	-0.0138
	(0.0135)	(0.0164)	(0.0852)
Alternative specific constant (ASC)	-0.525***	1.716***	
	(0.177)	(0.466)	
Control variables			
Age	-0.00638***	0.0125*	
	(0.00230)	(0.00748)	
Female	-0.0718	-0.254	
	(0.0751)	(0.253)	
Malay	-0.446***	0.518	
	(0.0987)	(0.409)	
Indian	0.456***	0.795*	
	(0.130)	(0.423)	
Other	-0.328	-1.364**	
	(0.203)	(0.595)	
Household size	0.000132	-0.0282	
	(0.0125)	(0.0295)	
Log of income	0.153***	-0.0269	
	(0.0202)	(0.0552)	
Private housing	0.809***	0.157	
	(0.143)	(0.353)	
Log-likelihood	-3929.9	-2629.2	
McFadden pseudo R^2	0.111	0.405	
AIC	7893.8	5308.4	
BIC	8019.6	5493.4	
No. of observations	12072	12072	
No. of respondents	503	503	

* p<0.1, ** p<0.5, *** p<0.01, robust standard errors are shown in brackets.

Note: Distance to the nearest construction site was interacted with the noise abatement variable. Control variables were interacted with the ASC. See Table 11-1 for a description of other variables. Standard deviations are given for random parameters. All non-cost attributes were assumed to have a normal distribution. The cost attribute was assumed to follow a log-normal distribution.

Results of the conditional logit regression indicate that a respondent preference for construction noise abatement increases as distance to the near construction site from a respondent's home decreases. This finding was in line with the intuition that respondents were more willing to pay for construction abatement if their homes were located closer to a construction site. If the home of a respondent was located nearer a construction site, the respondent was more likely to be adversely affected by construction noise, leading to a higher willingness-to-pay for construction noise abatement. Respondents' willingness-to-pay for construction noise was estimated to decrease by S$0.02 per dB for every metre increase in distance between the construction site and the respondents' home. This estimate was statistically significant at the 1% level of significance. The estimate suggests that respondents who lived 200m away from a construction site were willing to pay S$2 per dB less for construction noise abatement as compared to respondents who lived 100m away from a construction site.

In comparison, the coefficient on both the mean and standard deviation of distance to the nearest construction site was not statistically significant in the random parameter logit regression, suggesting that willingness-to-pay for construction noise abatement did not depend on the distance between construction sites and respondents' homes. This result suggests that future work can attempt to measure the ambient noise levels at respondents' homes in order to estimate the heterogeneous effect of ambient noise levels on willingness-to-pay for construction noise abatement.

11.3.2 Effect on willingness-to-pay for road noise abatement

Conditional logit and random parameter logit regressions were used to estimate the effect of distance between respondents' home and the nearest road on willingness-to-pay for road noise abatement. Similar to previous regressions in this chapter, both regressions included a full set of socio-economic variables to account for systematic taste variation. 214 respondents were excluded as they either were protest respondents or did not believe that the survey was consequential. In the random parameter logit regression, non-cost attributes were treated as normally distributed random parameters and the cost attribute was treated as a log-normally distributed random parameter.

Table 11-6 Heterogeneous effects of distance to nearest road willingness-to-pay for road noise abatement

	Conditional logit	Random parameter logit	
	(1)	(2)	
	Coefficient	Coefficient	Standard deviation
Cost	-0.00363***	-4.998***	2.128***
	(0.000354)	(0.175)	(0.204)
Reduction in noise level (dB)	0.0887***	0.161***	-0.134***
	(0.00857)	(0.0240)	(0.0166)
Distance to nearest road (m)	-0.0000957***	-0.0000336	0.0000636
	(0.0000224)	(0.0000888)	(0.000114)
Tighten regulations for vehicular noise emissions	0.139	-0.0433	0.0540
	(0.274)	(0.897)	(0.252)
Construct noise barriers along roads	-0.0473	-0.152	-0.475
	(0.270)	(0.898)	(0.322)
Construct roads with low-noise pavement material	0.306	0.429	0.924***
	(0.272)	(0.899)	(0.297)
Retrofit homes to reduce noise	-0.225	-0.338	1.151***
	(0.292)	(0.914)	(0.227)
Control variables			
Age	-0.0113***	0.0275**	
	(0.00323)	(0.0121)	
Female	0.122	0.747**	
	(0.0966)	(0.373)	
Malay	-0.206	-0.801	
	(0.148)	(0.538)	
Indian	0.454**	0.0694	
	(0.198)	(0.642)	
Other	-0.566*	0.167	
	(0.331)	(2.050)	
Household size	0.102***	-0.0113	
	(0.0323)	(0.124)	
Log of income	0.0795***	0.436***	
	(0.0217)	(0.112)	
Post-secondary	-0.169	-0.774*	
	(0.117)	(0.444)	
Bachelor degree or higher	-0.0113***	0.0275**	
	(0.00323)	(0.0121)	
Private housing	0.122	0.747**	
	(0.0966)	(0.373)	
Experienced living near construction sites	-0.206	-0.801	
	(0.148)	(0.538)	
Log-likelihood	-2219.5	-1499.3	
McFadden pseudo R^2	0.117	0.404	
AIC	4468.9	3042.7	
BIC	4571.4	3193.0	
No. of observations	6864	6864	
No. of respondents	286	286	

* p<0.1, ** p<0.5, *** p<0.01, robust standard errors are shown in brackets.

Note: Distance to the nearest road was interacted with the noise abatement variable. Control variables were interacted with the ASC. See Table 11-2 for a description of other variables. Standard deviations are given for random parameters. All non-cost attributes were assumed to have a normal distribution. The cost attribute was assumed to follow a log-normal distribution.

Similar to the results from the construction noise analysis results from the conditional logit regressions on data from the road noise survey indicate that respondents who lived further away from roads were less willing to pay for road noise abatement. These results may have been influenced by increased disamenities from roads noise when respondents live closer to roads.

Respondents' willingness-to-pay for road noise abatement was estimated to decrease by S$0.04 per dB for every metre increase in distance between the road and respondents' home. This estimate is statistically significant at the 10% level of significance. The results suggest that respondents who lived 200m away from a road were willing to pay S$4 per dB less for road noise abatement as compared to respondents who lived 100m away from roads.

In comparison to the conditional logit regressions, the random parameter logit regression suggests that distance to the nearest road did not influence respondents' willingness-to-pay for road noise abatement. Specifically, the regression coefficients on the mean and standard deviation of the were not statistically different from zero. These results mirrored those from the construction noise survey. Future studies can measure the ambient noise at respondents' homes to estimate the variation in willingness-to-pay for road noise dependent on ambient noise.

11.4 Conclusion

This chapter explored three heterogeneous factors that affect willingness-to-pay for noise abatement. First, the effect of privately-provided noise abatement was estimated. Prior private expenditure had opposite effects on the willingness-to-pay for construction and road noise abatement. Willingness-to-pay for publicly-provided construction noise abatement decreased when respondents have previously invested in private noise abatement measures. By comparison, respondents who have previously invested in private road noise abatement measures have a higher willingness-to-pay for public provision of road noise abatement.

Second, the effect of hearing sensitivity on willingness-to-pay for noise abatement was estimated. In the audio-based surveys, the quietest noise perceivable by respondents was measured with a hearing acuity test. Respondents' willingness-to-pay for construction and road noise abatement increased when respondents had more sensitivity hearing. This result was in line with the hypothesis that respondents who had more sensitive hearing were more likely to be annoyed by noise pollution, leading to a higher willingness-to-pay for reduction of noise levels.

Finally, the effect of distance to the nearest noise source on willingness-to-pay for construction or road noise abatement was estimated. Conditional logit regressions indicated that respondents who lived nearer to construction sites and roads were more willing to pay for noise reduction, possibly because these respondents were more adversely affected by disamenities from construction activity or roads. However, random parameter logit regressions indicate that respondents' willingness-to-pay for noise abatement was not dependent on the distance between respondents' homes and the nearest noise source. Future studies can measure the noise levels at respondents' homes to estimate the effect of ambient noise on willingness-to-pay for noise abatement.

This chapter completes the third part of the thesis (comprising Chapters 7 to 11). Results of the analysis presented in these chapters answered the research questions posed in Chapter 3. These results contribute to the literature and have policy implications. In the next chapter, the concluding chapter of this thesis, the contributions to the literature are discussed.

Chapter 12: Conclusion

Property rights for a quiet environment are not well-defined, potentially leading to noise emissions that are higher than optimal. In response to this market failure, governments can enact policies to correct the market failure and publicly provide noise abatement measures. However, policy-makers do not know *a priori* whether these policies result in a potential Pareto improvement that increases the welfare for society. Further, rent-seeking behaviour by noise sources and receptors can potentially lead to under- or over-provision of noise abatement, possibly reducing the welfare for society when compared to a lack of regulations (Fink 2016; Rosenberg 2016).

Ensuring that these measures result in a potential Pareto improvement require cost-benefit analysis. The framework of a cost-benefit analysis of noise abatement policies is introduced in Chapter 2. To conduct the cost-benefit analysis, information on the marginal benefits and marginal costs functions is required. Further, the noise transfer and noise aggregation functions enter as arguments in the marginal benefits function. The former two functions are derived from the economics literature, while the latter two have been extensively studied in the acoustics engineering literature. The marginal costs of noise abatement can be estimated by observing the market prices of these measures. By comparison, no markets exist for noise receptors to signal their preferences for noise abatement, and non-market valuation techniques are required to estimate the marginal benefits function.

The research conducted in this thesis focuses on estimating the marginal benefits of noise abatement. In the non-market valuation literature, non-market valuation techniques are broadly categorised into revealed preference methods and stated preference methods. The revealed preference approach can only be used to estimate the marginal benefits of noise abatement if the characteristics of the participants in the proxy market are known to the researcher. Since this information is not publicly available in Singapore, the stated preference method is used in this thesis.

A gap in the stated preference literature provided the motivation for the research in this thesis. Previous stated preference surveys described noise textually, requiring respondents to read and understand the descriptions when answering the questionnaire. However, textual noise description of noise is complex. Hence, choice modelling surveys that described changes to noise levels with audio recordings were designed, conducted, and analysed. Presenting respondents with audio recordings enable them to hear the noise levels when they make their choices, circumventing the challenges of designing a readily understandable text-based survey.

The results of the choice modelling surveys conducted in this thesis provide an estimate of the marginal benefits of noise abatement in Singapore. These results inform the cost-benefit analysis of publicly-provided noise abatement. This chapter concludes the thesis by presenting a summary of the key findings from this thesis. The implications of these findings on the formulation of future noise abatement policy are discussed. Finally, future research directions are proposed.

12.1 Discussion of research findings

12.1.1 Willingness-to-pay for construction and road noise

The research presented in this thesis sought to inform the cost-benefit analysis of construction and road noise abatement by estimating the marginal benefits of public provision of noise abatement. These marginal benefits functions are estimated with stated preference surveys. Unlike some other environmental goods (e.g., earmarking nature reserves, protecting natural habitats, and provision of recreational sites), describing changes to noise levels is complex. Noise is measured on the decibel scale, which maps non-linearly to respondents' perception of the loudness of noise levels. Hence, describing changes to noise levels with textual descriptions requires respondents to understand the textual description. Depending on the textual description used in the survey, researchers may also have to estimate the relationship between the described scenario and the physical measure of noise.

The stated preference surveys conducted in this thesis improved upon text-based survey questionnaires by describing changes to noise levels with audio recordings. This novel design enables respondents to perceive the noise levels when answering the questionnaire. Since respondents can hear the different noise levels, they did not have to understand textual descriptions of noise levels. This survey questionnaire design removes the ambiguity from textual descriptions and ascertains respondents' willingness-to-pay based on their subjective perception of different noise levels.

Chapter 8 presented the results of the construction noise survey. Results of the surveys suggest that respondents were willing to pay an annual payment of S$17 for a one-decibel reduction in construction noise over a period of three years on average. The willingness-to-pay of other attributes, such as the time in which construction activity is permitted to start and end as well as the duration of construction activity, were also estimated. These willingness-to-pay attributes enable the estimation of the marginal benefits accrued from a change in construction noise abatement policy.

These estimates appear to be high compared to current government spending to reduce construction noise below 75dB. For example, the estimates obtained from the study suggests that working adults in Singapore's labour force who are adversely affected by construction noise are collectively willing to pay S$22 million per year for a one-decibel reduction in noise levels.[78] By comparison, the Quieter Construction Fund (QCF) disbursed S$5.1 million between 2014 and 2019 to incentivise construction companies to reduce noise emissions (Tay 2019). The QCF was replaced by the Quieter Construction Innovation Fund (QCIF) in 2019. A total of S$2 million was earmarked to be disbursed over two years (Ng 2019). Hence, if the QCF and QCIF collectively reduces noise by one-decibel in Singapore, the marginal benefits from this reduction outweigh the costs of the policy.

Analysis to estimate the willingness-to-pay for road noise abatement was presented in Chapter 10. Respondents' willingness-to-pay was estimated to be an annual payment of S$20 per dB reduction in road noise. In addition to the willingness-to-pay for noise abatement, preferences for various road noise abatement measures were estimated. Random parameter logit regressions found that preferences for these noise abatement measures were heterogeneous in the sample.

The estimated marginal benefits from road noise abatement inform cost-benefit analysis of road noise abatement. While the costs of road noise abatement policies are not publicly available, the government can compare the estimated benefits of road noise abatement against estimated costs of proposed noise abatement policies. For example, if the government mandates that all cars in Singapore are required to install mufflers, the cost of this policy can be estimated

[78] Based on Singapore's resident labour force of 2.2 million (Statistics Singapore 2018b) and assuming that 60% of this population is adversely affected by construction noise (see Section 7.1.2 for summary statistics on annoyance with construction noise). If Singapore's total labour force was willing to pay $17 for a one-decibel reduction in noise levels, the aggregate marginal benefits of this policy is $38 million.

by taking the product of the unit costs of mufflers and the total number of cars in Singapore. Assuming a unit cost of S$100 per muffler (Moor 2015) and given Singapore's total car population of 636,000 in 2018 (LTA 2019), the total costs of this policy is estimated to be $64 million. Further, suppose that each muffler is effective for a period of five years and that the discount rate is 5%, then the annualised marginal benefits are S$15 million. For this policy to result in a potential Pareto improvement, the policy marginal benefits of the policy must be more than S$14 million. Assuming Singapore's working adult population is willing to pay S$20 per annum each for one-decibel reduction in noise, the aggregate willingness-to-pay is estimated to be S$18 million per year[79], which suggests that the policy to install mufflers in all cars needs to result in less than one-decibel reduction in noise levels on average for the policy to yield a potential Pareto improvement.

In summary, the marginal benefit of construction and road noise abatement estimated in this thesis can inform cost-benefit analysis of government policies to reduce noise. Conducting a cost-benefit analysis enables the estimation of the welfare change arising from a change in government policy. This systematic estimation of welfare change can potentially prevent government failures arising from lobbying efforts by noise sources or receptors.

12.1.2 Effects of respondents' understanding on preferences for noise abatement

In addition to conducting audio-based surveys, a text-based survey was also to estimate the heterogeneous effect of different attribute representations on respondents' willingness-to-pay for construction noise abatement. As discussed in Chapter 2, noise is difficult to describe textually and respondents may not fully understand textual descriptions of changes to noise levels. In order to ascertain respondents' understanding of the information provided in the text-based questionnaire, test questions were also included in the questionnaire.

Chapter 9 analysed the data collected in the text-based survey and compared these results to the audio-based survey. Results indicate that respondents to the audio-based survey questionnaire stated a higher willingness-to-pay than the text-based survey questionnaire on average. These results extend the literature on the effect of attribute representation on respondents' preferences (Bushong et al. 2010; Kaushali, Toner & Chen 2018; Kragt & Bennett

[79] Based on Singapore's resident labour force of 2.2 million and assuming that 40% of this population is adversely affected by road noise (see Section 7.2.2 for summary statistics on annoyance with road noise). If Singapore's total labour force (including foreigners) was assumed to willing to pay $20 for a one-decibel reduction in noise levels, the aggregate marginal benefits of this policy is $30 million.

2012; Windle & Rolfe 2014), which found that different attribute representation can result in different estimates of marginal benefits.

The research conducted in this thesis indicates that respondents' understanding of the information provided in a text-based questionnaire may be a channel to explain the differences in average willingness-to-pay in the audio- and text-based surveys. Specifically, the heterogeneous effect of correct responses to the test questions on willingness-to-pay for noise abatement was estimated. Results indicate the respondents' willingness-to-pay increased with a better understanding of the questionnaire.

The results are particularly important since summary statistics suggest that a large proportion of survey respondents did not fully understand the information provided in the survey questionnaire. Further, questions on respondents' self-reported understanding was not a good predictor of respondents' understanding of the information in the questionnaire. Since respondents' willingness-to-pay for noise abatement increased with a better understanding of the survey questionnaire, these results suggest that previous studies may have underestimated the marginal benefits of noise abatement. Consequently, when feasible, future studies should use survey questionnaires that described changes to noise levels with audio recordings to obtain a more accurate estimate of the marginal benefits of noise abatement.

12.1.3 Heterogeneous preferences for noise abatement

Heterogeneity in willingness-to-pay for noise abatement was examined in Chapter 11. Three sources of heterogeneity were analysed, namely prior private spending on noise abatement, hearing sensitivity, and distance between noise sources and respondents' residences.

Unlike some other environmental goods (e.g., emission of ozone), noise pollution is a local pollutant and residents can take private defensive measures to limit exposure to noise pollution. Hence, public provision of noise abatement is in addition to prior private spending on noise abatement measures. However, the relationship between the prior private provision of noise abatement and the willingness-to-pay for publicly-provided noise abatement is not known *a priori*.

Private provision of noise abatement was found to be negatively correlated with willingness-to-pay for publicly-provided construction noise abatement. This result suggests that respondents were less willing to pay for public provision of construction noise abatement if they have previously installed private measures to reduce noise. It also suggests that publicly-provided construction noise abatement can potentially focus on new estates where residents have not had an opportunity to install privately-provided noise abatement measures as the marginal benefits for publicly-provided measures are higher in these estates.

By comparison, privately-provided noise abatement was found to be positively correlated with publicly-provided road noise abatement measures. The difference in the effect of privately-provided noise abatement on publicly-provided measures may have been due to differences in the duration of noise pollution. Construction noise is temporary and will cease upon completion of the construction activity. However, road noise is permanent and residents annoyed by road noise may be more likely to install private abatement measures. These results may be driven by the residents who are annoyed by road noise selectively installing noise abatement measures privately.

Second, the effect of hearing sensitivity on willingness-to-pay for noise abatement was estimated. Unlike previous stated preference surveys estimating the willingness-to-pay for noise abatement, the quietest noise perceivable by respondents was measured with a hearing acuity test in the audio-based questionnaires. Respondents' willingness-to-pay for construction and road noise abatement increased when respondents had more sensitivity hearing. This result was in line with the hypothesis that respondents who had more sensitive hearing were more likely to be annoyed by noise pollution, leading to a higher willingness-to-pay for reduction of noise levels. These results also inform the design of public noise abatement policies affecting noise sensitive areas, such as schools and hospitals.

Finally, the effect of distance to the nearest noise source on willingness-to-pay for construction or road noise abatement was estimated. Distance to the nearest construction site or road proxied for the noise pollution caused by these noise sources. Analysis suggests that respondents who lived nearer to construction sites and roads were more willing to pay for noise reduction, possibly because these respondents were more adversely affected by disamenities from construction activity or roads.

12.2 Limitations and future research directions

The discussions presented in Section 12.1 summarised key research findings and their policy implications. This section highlights the limitations and caveats of these research findings. Fully addressing these limitations is beyond the scope of this thesis, however, future research directions are proposed in response to these limitations.

12.2.1 Anomalous responses

As discussed in Section 7.3, the proportion of anomalous respondents was high when compared to other stated preference studies (see, for example, Meyerhoff & Liebe (2010) for a meta-analysis). Several reasons may have contributed to the high proportions of protest responses and respondents who did not view the survey as being consequential.

First, in spite of the current allocation of property rights, where property rights are not well-defined when the ambient noise levels are below 75dB, respondents may have felt that they deserved to be compensated for suffering the damages due to noise pollution. Respondents may also have felt that from a fairness viewpoint, noise sources should be penalised since they caused the noise. Consequently, respondents may have rejected the willingness-to-pay frame of the survey questionnaires.

Second, respondents may also be sceptical that the funds collected by the government will be used effectively in reducing noise pollution. As discussed in Section 5.5, there has been discussion in Singapore’s mainstream media on the effective use of government funds in response to a proposed increase in the tax rate (Chia 2018; Heng 2018). Alternative media sources have also been criticised the efficient use of funds in Singapore (Leong 2017; Xavier 2019). These discussions may have affected Singaporeans’ perception of the effectiveness of government policy, in turn, affecting the protest respondents in this survey.

Third, the high proportion of respondents who felt that their responses to the survey will not affect future government policy may have been due to the ineffectiveness of existing noise control policies. As discussed in Section 2.1, the Singapore government has implemented numerous policies to control noise pollution. However, a majority of respondents to both the construction and road noise surveys said that they were annoyed by noise from these sources (see Sections 7.1.2 and 7.2.2). Hence, respondents may be cynical that the government will not implement tighter controls on noise sources in spite of their responses to this survey.

The factors contributing to the anomalous responses in a stated preference survey conducted in Singapore can be examined in future research. This research can potentially explain the proportion of anomalous responses given different political climates.

12.2.2 Perception vs physical measure of noise levels

The analysis presented in Chapters 8 to 11 of this thesis estimated the willingness-to-pay for decibel changes in noise abatement. The physical measure of noise, i.e., the decibel, was used as it was the unit that policy-makers used to set noise abatement policy (see, for example, Foo (1996) and Gilchrist & Allouche (2005)). However, as discussed in Section 2.5, the decibel scale is derived by taking the logarithm of the sound pressure. Further, the decibel scale does not scale linearly with an individual's perception of noise. For instance, studies from psychoacoustics found that a 10dB decrease in noise levels corresponds with approximately a halving of perceived loudness (Fastl & Zwicker 2007). This measure of noise differs from most other environmental goods, which are measured in linear units. For example, changes to forest conservation policy typically measure changes to the area of protected forests.

The findings from the thesis suggest that preferences for noise abatement may be non-linear in sound pressure (measured in Pascals) and perception of noise. Specifically, a statistically significant linear relationship between willingness-to-pay and decibels, suggest diminishing willingness-to-pay for linear changes in sound pressure and perception of noise levels.

Future studies can estimate the willingness-to-pay for changes to sound pressure and perception of noise levels. These studies contribute to the economic valuation literature, audiology, and acoustic engineering literature.

12.2.3 Survey design and implementation

In the surveys conducted in this thesis, the baseline levels of noise were standardised across all survey questionnaires. Further, the noise recording used in the audio-based construction and road noise surveys were obtained from a typical construction site or road.

Presenting all respondents with the same baseline noise level and the same recorded noise caused three limitations. First, respondents' preferences for noise abatement may depend on the frequency of noise, which does not vary given that the same recording was presented to all respondents. Second, the effect of privately-provided noise abatement on preferences for publicly-provided noise abatement cannot be estimated since the baseline level of noise is the same for all choice sets. Third, respondents' preferences for publicly-provided noise abatement may depend on the ambient noise level, which cannot be varied in this survey design.

Another limitation of the surveys conducted in this study was that each sound clip was only ten seconds long. The length of the sound clips was chosen to ensure that the survey questionnaire was not excessively long. However, a short sound clip precludes the estimation of the longer-term effects of noise pollution. A commonly cited cause of annoyance from noise pollution is intermittent noise (Fastl & Zwicker 2007), which refers to periods of quiet interspersed with spikes in the noise level. Further, the persistence of noise can also affect the respondents' willingness-to-pay for noise abatement. However, given the duration of the sound clips, it was not possible to estimate the effects of willingness-to-pay for intermittent noise.

Pivot designs have been used to account for the respondents' environment, prior experience, and knowledge base when designing the attributes of a stated preference survey (Hess & Rose 2008). In a pivot design, respondents are presented with a choice sets that include a status quo option that represent the exact levels of each respondents' recent experience and the attributes are changes to this baseline alternative (Hensher 2004; Hensher & Greene 2003). Pivot designs are consistent with psychological theories. For example, prospect theory argues that individuals use decision heuristics when making choices and the context in which individuals makes their choices is an important determinant of the choice heuristic (Kahneman & Tversky 1979).

While pivot designs have several attractive properties, a key constraint in the implementation of pivot design is the need to change the attributes on-the-fly. Previous stated preference surveys used textual descriptions which can be changed with relative ease if the choice sets were presented to respondents electronically. However, specific to an audio-based survey, obtaining the background noise level requires recording of ambient noise before the survey commences. Next, these noise recordings need to be manipulated on-the-fly so that the designed noise levels are presented to respondents. Given the complexity and difficulty in coding this procedure, a pivot design was not used in this study.

Advances in technology can potentially enable the use of pivot design and the estimation of noise characteristics. For example, a mobile application can be designed so that noise is recorded on the respondents' phone, which plays noise over a longer period (perhaps over the course of several days and nights to estimate the effect of willingness-to-pay for day- and night-time noise). Respondents then report their annoyance and willingness-to-pay for different noise levels. Since respondents are using their mobile phones, they can complete the survey questionnaire privately and over a longer duration. Such a questionnaire design immerses a respondent in their surroundings and enables an analysis of a wide range of different types of sound. If the survey was conducted over an extended period, such as before and after a respondent installs private noise abatement measures, the differential effect of noise abatement can also be estimated.

12.2.4 The design of noise abatement policies

This thesis explored the willingness-to-pay for construction and road noise abatement. Together with information on the marginal costs of noise abatement as well as the physical characteristics of noise, the net benefits from noise abatement policies can be estimated. However, the marginal costs function has not been analysed in this thesis. Future studies can examine the marginal costs function to complete the cost-benefit analysis framework presented in Chapter 2.

Currently, noise abatement policies in Singapore have generally been command-and-control policies, where the government mandates a limit to the noise level or restricts the pieces of construction equipment or vehicles that are permitted (Singapore Statutes 2011). Future studies can examine market-based mechanisms as alternatives to command-and-control policies to incentivise noise sources to bear the external costs of noise emission. An example of such market-based mechanisms includes a tax on noise sources such that the noise source internalises the external costs of noise pollution to residents. Taxes have been used in a wide range of environmental goods, such as management of water use, fishery, forestry and wetlands (Bennett 2015; Freeman & Kolstad 2006; Perman et al. 2003).

The government has also attempted to reduce noise abatement. For example, the government earmarked funds for the Quieter Construction Fund and the Quieter Construction Innovation Fund to subsidise the purchase of quieter construction equipment. The effectiveness of such abatement measures has not been examined. Future research can also examine the possibility of a reverse auction where noise sources are asked to tender for the provision of noise abatement. The tender bids will be ordered from the lowest priced tender to the highest priced. This method of eliciting the marginal costs of provision of environmental goods has been used to value conservation programmes in the US as well as Australia (see Reichelderfer & Boggess (1988) and Eigenraam et al. (2018) respectively). While these policies can potentially result in low additionality projects, analysis of the welfare change from a reserve auction compared to the subsidies currently provided can inform which policy is preferred.

While market-based mechanisms have been used to control other types of pollution and incentivise conservation of the environment, these mechanisms have not been widely used to control noise pollution. Unlike some other pollutants, the relationship between noise emissions at the source and noise perceived at the receptor is dependent on non-linear transfer and aggregating functions. Consequently, the design and implementation of market mechanisms to control noise pollution may be a challenge that future research can examine.

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Appendix 1: Coding of audio-based survey questionnaire

Hypertext mark-up language (HTML), Cascading Style Sheets (CSS), and JavaScript programming languages were used to design the survey questionnaire. In order for the survey questionnaire to be compatible with the survey company's back-end data recording server, the entire survey is written in one HTML document. A JavaScript command was used to show only relevant sections of the survey questionnaire as a respondent completes each section of the questionnaire.

Specific to the choice cards in the questionnaire, all choice cards are first prepared in HTML. An example of the HTML codes for one choice card is shown below. The table is nested in `<div id="choice1">` tag. Each row in the table is defined by the `<tr>` tag and each have separate classes. In addition, the 'Play' and 'Pause' buttons in the choice set are each defined to have separate classes. Finally, a picture is included in the background of the choice set by defining: `<img src="images/Picture1.gif">`.

```
<div id="choice1">
 <div class="demostart">
 <p>Press this box to start</p>
 </div>

 <div class="time"><img src="images/Picture1.gif">

 <table>
 <tr>
 <th>Policy</th>
 <th>Permitted Construction Timing</th>
 <th>No Work Rule</th>
 <th>Change in Construction Duration</th>
 <th>Construction Noise</th>
 <th>One-off Charge</th>
 <th>Your Choice</th>
 </tr>

 <tbody class="statusquo">
 <tr>
 <td>Status Quo</td>
 <td>7am-7pm</td>
 <td>
 <ul>
 Work prohibited on:
 <li>Sundays</li>
 <li>Public Holidays</li>
 </ul>
```

```
 </td>
 <td>No Change</td>
 <td>
 <p class="statusquoplay">Play</p>
 <p class="statusquopause">Pause</p>
 </td>
 <td> S$0</td>
 <td><form><input type="radio" value="Set A Base"
name="formsplus[fp-radio][Choice_Set_A][]"></form></td>
 </tr>
 </tbody>

 <tbody class="opt1">
 <tr>
 <td>1</td>
 <td>8am-6pm</td>
 <td>
 <ul>
 Work prohibited on:
 <li>Saturdays</li>
 <li>Sundays</li>
 <li>Public Holidays</li>
 </ul>
 </td>
 <td>Increase by 3 months</td>
 <td>
 <p class="opt1play">Play</p>
 <p class="opt1pause">Pause</p>
 </td>
 <td> S$100</td>
 <td><form><input type="radio" value="Set A Option1"
name="formsplus[fp-radio][Choice_Set_A][]"></form></td>
 </tr>
 </tbody>

 <tbody class="opt2">
 <tr>
 <td>2</td>
 <td>9am-5pm</td>
 <td>
 <ul>
 Work prohibited on:
 <li>Saturdays</li>
 <li>Sundays</li>
 <li>Eve of Public Holidays</li>
 <li>Public Holidays</li>
 </ul>
 </td>
 <td>Increase by 12 months</td>
```

```
 <td>
 <p class="opt2play">Play</p>
 <p class="opt2pause">Pause</p>
 </td>
 <td> S$200</td>
 <td><form><input type="radio" value="Set A Option2"
name="formsplus[fp-radio][Choice_Set_A][]"></form></td>
 </tr>
 </tbody>

 </table>
 </div>

 <div class="pause">
 <p><a href="pause.html">Click here to pause<br>or terminate
the survey.</a></p>
 </div>

 <div class="footer">
 <p>Next</p>
   </div>

 <audio class="player"></audio>
 <audio class="choices" loop="loop"></audio>
</div>
```

After setting up all eight choice sets, a series of variables are defined. These variables correspond to the sound clips to be played in each choice set.

```
 var soundlist1 = ["sounds/construction75.wav", // baseline
 "sounds/construction65.wav", // option 1
 "sounds/construction55.wav"]; // option 2

 var soundlist2 = ["sounds/noiseh15vol90.wav",
 "sounds/noisel15vol70.wav",
 "sounds/noisel05vol60.wav"];

 var soundlist3 = ["sounds/noiseh15vol90.wav",
 "sounds/noisel15vol70.wav",
 "sounds/noisel05vol60.wav"];

 var soundlist4 = ["sounds/noiseh15vol90.wav",
 "sounds/noisel15vol70.wav",
 "sounds/noisel05vol60.wav"];

 var soundlist5 = ["sounds/noiseh15vol90.wav",
 "sounds/noisel15vol70.wav",
 "sounds/noisel05vol60.wav"];

 var soundlist6 = ["sounds/noiseh15vol90.wav",
```

```
 "sounds/noisel15vol70.wav",
 "sounds/noisel05vol60.wav"];

 var soundlist7 = ["sounds/noiseh15vol90.wav",
 "sounds/noisel15vol70.wav",
 "sounds/noisel05vol60.wav"];

 var soundlist8 = ["sounds/noiseh15vol90.wav",
 "sounds/noisel15vol70.wav",
 "sounds/noisel05vol60.wav"];
```

As discussed previously, all choice sets were prepared on a single HTML document. Hence, all choice cards were hidden and only the first choice set is shown.

```
    S$("document").ready(function() {
    S$("#choice1 .time").hide()
    S$("#choice2").hide()
    S$("#choice3").hide()
 S$("#choice4").hide()
 S$("#choice5").hide()
 S$("#choice6").hide()
 S$("#choice7").hide()
 S$("#choice8").hide()
 S$(".footer").hide()
   });
```

Next, a listener was coded to select elements of the active choice set. For example, when the respondent clicks on the first choice set, the listener selects all elements in this choice set, as marked by the class tags.

```
 S$("#choice1 .demostart").mouseup(function(){
 var _demostart = document.querySelector("#choice1
.demostart");
 var _time = document.querySelector("#choice1 .time");
 var _form = document.querySelectorAll("#choice1 form");
 var _statusquo = document.querySelector("#choice1
.statusquo");
 var _statusquoplay = document.querySelector("#choice1
.statusquoplay");
 var _statusquopause = document.querySelector("#choice1
.statusquopause");
 var _opt1 = document.querySelector("#choice1 .opt1");
 var _opt1play = document.querySelector("#choice1
.opt1play");
 var _opt1pause = document.querySelector("#choice1
.opt1pause");
 var _opt2 = document.querySelector("#choice1 .opt2");
 var _opt2play = document.querySelector("#choice1
.opt2play");
```

```
 var _opt2pause = document.querySelector("#choice1
.opt2pause");
 var _pause = document.querySelector("#choice1 .pause");
 var _footer = document.querySelector("#choice1 .footer");
 var _player = document.querySelector("#choice1 .player");
 var _choices = document.querySelector("#choice1 .choices");
 choices(soundlist1, _demostart, _time, _form, _statusquo,
_statusquoplay, _statusquopause,
 _opt1, _opt1play, _opt1pause, _opt2, _opt2play, _opt2pause,
_pause, _footer, _player, _choices)
 });

 S$("#choice1 .footer").mouseup(function(){
 S$("#choice1").hide()
 S$("#choice2").show()
 S$("#choice2 .time").hide()
 });
```

The listener also calls the function 'choices'. Choices first plays each sound clip in the selected choice set. In order to play the sound clips, an immediately invoked function expression (IIFE) is used (see https://borgs.cybrilla.com/tils/javascript-for-loop-with-delay-in-each-iteration-using-iife/ for a description of IIFE function and setting delays within loops in Java).

The 'choices' function also contain listeners to toggle between playing and pausing of each sound clip. For example, if a respondent presses on the 'Play' button of the status quo option, the function pauses the sounds from all other options and only plays the sound clip of the status quo option.

```
 function choices(soundlist, _demostart, _time, _form,
_statusquo, _statusquoplay, _statusquopause,
 _opt1, _opt1play, _opt1pause, _opt2, _opt2play, _opt2pause,
_pause, _footer, _player, _choices) {
 S$(_demostart).hide();
 S$(_time).show();
 S$(_form).hide();

 var i=0
 var j=i
 _player.src=soundlist[i];
 _player.play()
 S$(_statusquo).addClass("statusquodemo")

 for (var i = 1; i < 3; i++) {
 (function (i) {
```

```
setTimeout(function () {
if (i==1) {
console.log(i)
_player.src=soundlist[i];
_player.play()
S$(".statusquodemo").removeClass("statusquodemo")
S$(_opt1).addClass("opt1demo")
} else if (i==2) {
console.log(i)
_player.src=soundlist[i];
_player.play()
S$(".opt1demo").removeClass("opt1demo")
S$(_opt2).addClass("opt2demo")
}
j=i
}, 10100*i);
})(i);
};

setTimeout(function () {
S$(_form).show()
S$(".opt2demo").removeClass("opt2demo")

S$(_statusquoplay).mouseup(function() {
_choices.src=soundlist[0];
_choices.play()
S$(_statusquo).addClass("statusquodemo")
S$(".opt1demo").removeClass("opt1demo")
S$(".opt2demo").removeClass("opt2demo")
})

S$(_opt1play).mouseup(function() {
_choices.src=soundlist[1];
_choices.play()
S$(_opt1).addClass("opt1demo")
S$(".statusquodemo").removeClass("statusquodemo")
S$(".opt2demo").removeClass("opt2demo")
})

S$(_opt2play).mouseup(function() {
_choices.src=soundlist[2];
_choices.play()
S$(_opt2).addClass("opt2demo")
S$(".opt1demo").removeClass("opt1demo")
S$(".statusquodemo").removeClass("statusquodemo")
})

S$(_statusquopause).mouseup(function() {
_choices.pause()
```

```
S$(".statusquodemo").removeClass("statusquodemo")
S$(".opt1demo").removeClass("opt1demo")
S$(".opt2demo").removeClass("opt2demo")
})

S$(_opt1pause).mouseup(function() {
_choices.pause()
S$(".statusquodemo").removeClass("statusquodemo")
S$(".opt1demo").removeClass("opt1demo")
S$(".opt2demo").removeClass("opt2demo") })

S$(_opt2pause).mouseup(function() {
_choices.pause()
S$(".statusquodemo").removeClass("statusquodemo")
S$(".opt1demo").removeClass("opt1demo")
S$(".opt2demo").removeClass("opt2demo")
})

S$(_form).mousedown(function(){
S$(_footer).show()
_choices.pause()
})

}, 30400);
};
```

Appendix 2: Calibration of noise recordings[80]

Noise is perceived as fluctuation of pressure. When these changes in pressure is recorded on a recording device the change in pressure is encoded as a series of different voltages. These voltages will be passed as electronic signals to the sound reproduction device, which will reproduce the sound.

To calibrate the noise levels, a noise recording device was first calibrated. The noise recording device is a Zoom H4n recorder with BSWA BR2022 binaural microphones. A 1Pa test tone, with a sound pressure level of 94dB and a frequency of 1kHz was played to the recorder. The recorder encodes the sound to a.mp4 file, which records the voltage to be passed to a sound reproduction device. The calibration factor was estimated based on the ratio of the root mean squared sound pressure and the root mean squared voltage in the .mp4 file.

A 1kHz test tone with a root mean squared voltage of 0.1V was then generated in MatLab and played on the sound reproduction device, namely, a pair of Audio Technica M40x headphones connected to a Samsung Galaxy Tab 5. The loudness of this test tone was estimated by recording the test tone on the Zoom H4n recorder with the BSWA BR2022 microphones. The gain of the sound reproduction device was estimated based on the ratio of the root mean square voltage of the test tone and the measured loudness of the noise produced from the headphones.

The estimated gain provides a correlation between the root mean square voltage in the .mp4 file and the root mean square sound pressure. The gain was then used to calibrate the test tones used in the survey questionnaire.

[80] Assistance from Dr Lau Siu Kit and Dr Chen Han Chi is acknowledged in the design of the calibration protocol. Dr Lau Siu Kit has a PhD in acoustics and is currently a Senior Lecturer in NUS' School of Design and Environment. Dr Chen Han Chi has a PhD in acoustic signal processing and is currently a research fellow at the ANU.

Appendix 3: Audio-based construction noise survey questionnaire

Introduction

Dear participant,

We are from Media Research Consultants and we are conducting a survey on behalf of the Singapore Government, in collaboration with the Australian National University (ANU). The survey will help us understand your views on construction noise in Singapore in order for us to propose policies to control construction noise.

Your participation in this survey is entirely voluntary and your responses and identity will be kept strictly confidential. The survey will take about 30 minutes. Thank you very much for your time.

Research Team

- Leong Chi Hoong, PhD Candidate, Australian National University,
  College of Asia and the Pacific, Crawford School of Public Policy
  chihoong.leong@anu.edu.au
- Jeff Bennett, Professor, Australian National University,
  College of Asia and the Pacific, Crawford School of Public Policy
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Participant information sheet

General Outline of the Project

- Description and methodology: Estimate the willingness-to-pay for a reduction in construction noise among residents in Singapore with a choice modelling survey.
- Participants: We will be surveying a representative sample of 1,000 individuals through a door-to-door survey.

Participant Involvement

- Voluntary participation and withdrawal: Your participation in this research is voluntary. You may decline to take part or to withdraw from the research without providing an explanation at any time until you have submitted the survey. As this survey is designed to be confidential you would not be able to withdraw your response upon submission of the completed survey questionnaire.
- What does participation in this survey entail?: You are invited to take part in a survey to ascertain the willingness-to-pay for a reduction in construction noise. The survey questionnaire consists of three main sections: (i) a series of questions where you choose between different types of construction noises and associated costs; (ii) a hearing acuity test to understand your sensitivity to sounds; and (iii) a demography section to understand your background.
- Location and duration: The survey is being conducted at the doorstep of your home and will require approximately 30 minutes to complete.
- Remuneration: We will be providing an incentive of S$10 worth of NTUC vouchers for participation in this survey to compensate for your time to take part in this survey.
- Risks: You will have full control over whether you will like to proceed with the survey and you can terminate the survey at any point. If, for any reason, you will like to stop participation, a save button is provided for you to stop participation immediately.

- Benefits: This project will provide us with an estimate of the benefits associated with the abatement of construction noise in Singapore, which would, in turn, enable us to propose policies to regulate construction noise.

Exclusion Criteria

- Participant limitation: You can only participate in this survey if you are a resident in Singapore and aged 18 or over.

Confidentiality

- Confidentiality: We will keep your identity confidential as far as allowed by law, unless you elect to be named within the research. Access to the data you provide will be restricted to the research team, and identifying details will be stored separately from the rest of the research data. Published results will only be reported in aggregate, and you will not be identifiable within published outputs unless you have elected otherwise.

Privacy Notice

- In collecting your personal information within this research, the ANU must comply with the Australia's Privacy Act 1988. The ANU Privacy Policy is available at https://policies.anu.edu.au/ppl/document/ANUP_010007and it contains information about how a person can: (i) Access or seek correction to their personal information; and (ii) Complain about a breach of an Australian Privacy Principle by ANU, and how ANU will handle the complaint.

Data Storage

- Where: Data will be securely stored on password protected computers at the Australian National University.
- Duration: All research data will be retained and securely stored for at least five years following publications arising from research. Data will have no identifying details attached.
- Handling of data following the required storage period: After the storage period, the data will be archived at the Crawford School of Public Policy for use in later research, including potentially by other researchers.

Queries and Concerns

Please feel free to contact us at the following email addresses if you have any other questions related to our survey:

1. Leong Chi Hoong, PhD Candidate, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy chihoong.leong@anu.edu.au, +65 9030 1763
2. Jeff Bennett, Professor, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy jeff.bennett@anu.edu.au

Contacts in Singapore: If you would like to contact an officer based in Singapore, please get in touch with:
3. Melinda Poh, Senior Assistant Director, Environmental Behavioural Sciences and Economics Research Unit melinda_poh@mewr.gov.sg
4. Royston Toh, Assistant Director, Environmental Behavioural Sciences and Economics Research Unit royston_toh@mewr.gov.sg

Ethics Committee Clearance
The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol 2017/604). If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Consent for Participation

I have read and understood the Information Sheet you have given me about the research project, and I have had any questions and concerns about the project addressed to my satisfaction.

1. The list of concerns (if any) are as follows:
____

2. I agree to participate in the project

1	Agree	**CONTINUE**
2	Do not Agree	**TERMINATE**

3. I understand that, should I wish to, I can end the survey at any point.

1	Yes
2	No

About this Survey

This survey is about construction noise in Singapore and consists of four parts:

- **Part 1: About you.** We ask a few questions about you.
- **Part 2: Your choices.** We ask you to choose between different types of construction noise.
- **Part 3: Hearing acuity test.** We will play several sounds to understand your sensitivity to sounds.
- **Part 4: About you.** We ask a few more questions about you.

SECTION 1: ABOUT YOU

1. Are you a Singapore resident (either Singapore citizen or permanent resident)?

1	Yes	**CONTINUE**
2	No	**TERMINATE**

2. What is your age?

1	Below 18 years old	**TERMINATE**
2	18-19 Years old	**<<Check Quota>>**
3	20-24 Years old	**<<Check Quota>>**
4	25-29 Years old	**<<Check Quota>>**
5	30-34 Years old	**<<Check Quota>>**
6	35-39 Years old	**<<Check Quota>>**
7	40-44 Years old	**<<Check Quota>>**
8	45-49 Years old	**<<Check Quota>>**
9	50-54 Years old	**<<Check Quota>>**
10	55-59 Years old	**<<Check Quota>>**
11	60-64 Years old	**<<Check Quota>>**
12	65-69 Years old	**<<Check Quota>>**
13	70 Years old and above	**<<Check Quota>>**

3. Have you lived near a construction site before?

1	Yes
2	No

4. If you have lived near a construction site, how annoying was the construction noise experienced?

1	Not annoying at all
2	A bit annoying
3	Annoying
4	Very annoying
5	Exceedingly annoying
6	Not applicable, I have not lived near a construction

5. Have you ever been diagnosed with severe migraines by a medically-certified doctor?

1	Yes
2	No

6. Have you ever been diagnosed with tinnitus by a medically-certified doctor?

1	Yes
2	No

7. Do you have any existing hearing disorders?

1	Yes, please specify:_________________________________
2	No

SECTION 2: CONSTRUCTION NOISE IN SINGAPORE

Singapore is geographically small, highly urbanised and densely populated. The rapid pace of development has led to a high number of construction sites in Singapore. However, residents living near construction sites may be affected by higher levels of noise.

In this section of the survey, we will like to find out how much you are willing to pay for a reduction in construction noise. Your responses to this section are important. Survey results will inform policies that the Government can implement to control construction noise.

Demonstration

In order to illustrate the noise generated by a construction site, we will first play a 10-second recording of construction noise in Singapore.

If you would like to raise any concerns when we are playing the construction noise, please pause the survey and inform the surveyor.

Press this box to start

You can proceed to the next page after the sound clip has ended.

Perception of Construction Noise

1. Was the recorded construction noise you just heard similar to actual construction noise that you typically encounter?

1	Yes
2	No
3	Not applicable as I have not encountered construction noise before

2. How annoying was the construction noise you just heard?

1	Not annoying at all
2	A bit annoying
3	Annoying
4	Very annoying
5	Exceedingly annoying

3. If you were staying near a construction site causing this level of noise, how would you reduce the impact of the noise? [Multiple Answers]

1	Install sound-proof, double glazed windows.
2	Close windows when construction noise is loud.
3	Close window and switch on air-conditioning when construction noise is loud.
4	Use of ear plugs.
5	Leave house to avoid construction noise.
6	Do not undertake any measures.
7	Others, please specify: ___________________________________

4. How much have you previously spent on these measures to reduce the impact of construction noise?

Amount of Money Spent SGD:________

5. Which of the following construction noise is sufficiently quiet such that you will not be willing to pay for further noise reduction? (Please press on the play button to hear the sound clips.)

1	Sound Clip 1
2	Sound Clip 2
3	Sound Clip 3
4	Sound Clip 4
5	Sound Clip 5
6	None of the above as I am willing to pay even if the sound is as quiet as sound clip 5
7	None of the above as I am not willing to pay even if the sound is as loud as sound clip 1

<u>Mitigation Measures:</u>

What can be done to reduce construction noise?
The next section of the survey seeks to understand your preferences to reduce construction noise in Singapore.

Noise from construction sites are currently regulated to be below 75dB averaged over a 12hr interval as measured from the nearest house. In order to further reduce the impact of construction noise, the following policies could be implemented.

1) Regulate construction equipment and practices in order to encourage construction companies to emit lower levels of noise.
2) Reduce the noise emitted from construction sites with noise barriers.
3) Retrofit windows with sound-proof double-glazed windows.
4) Disallow or restrict construction activities at nights and on weekends as well as public holidays.

These policies could change the following factors:
1) **Loudness of construction noise**: different policies could result in different noise levels.

2) **Time when construction activity starts and ends**: construction activity could start later in the morning or end earlier in the evenings.
3) **Days when construction activity is prohibited**: construction activities could be prohibited on Sundays only or on both Saturday and Sunday.
4) **Length of construction activity**: more construction work could be carried out at the same time – leading to higher levels of noise, but shorter construction duration.
5) **Annual payment**: these changes will have different costs, funded by a compulsory annual payment to a community fund, which is administered by the government. You will only have to contribute to the fund when there is ongoing construction activity.

Choice Card Layout

Consider a construction site near your house. This site will take around three years to complete.

In the following eight scenarios, we would like to ask you to choose between three different options. Each option will outline different methods to control noise from the construction site near your house, leading to different experiences.

In the first row, we present the current situation, where no additional measures to control construction noise is implemented.
In the second and third rows, we present possible changes to policies to reduce construction noise.
An example of a question is shown below:

Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

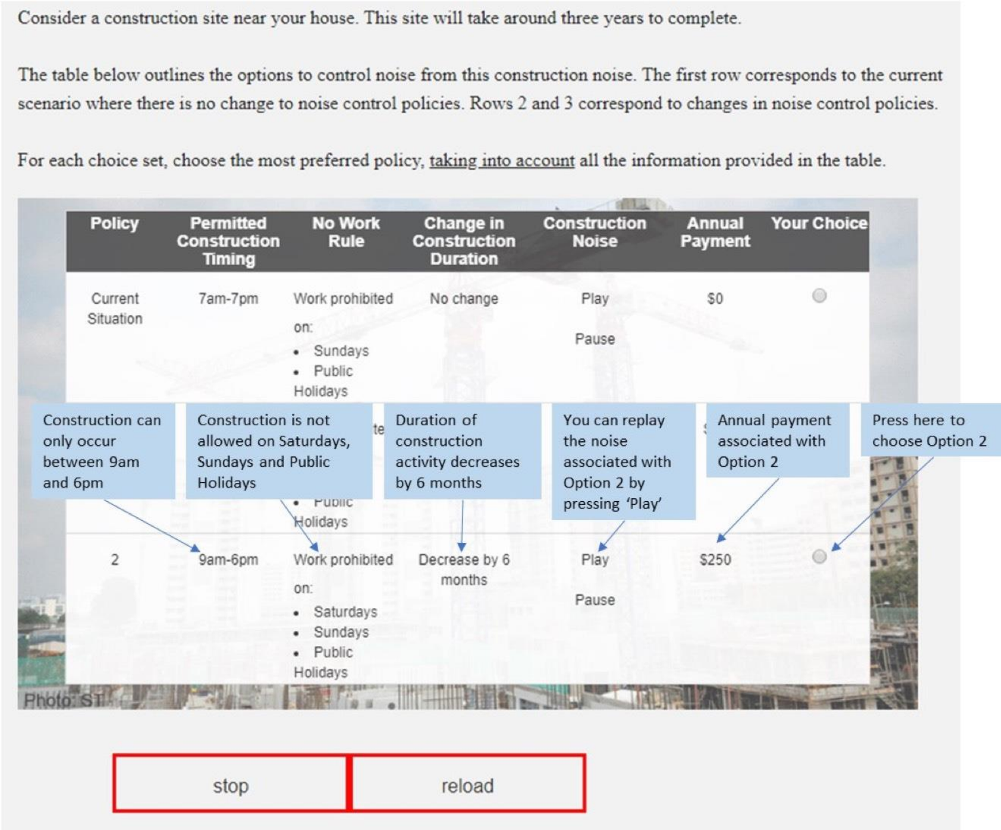
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Your Choice
Current Situation	7am-7pm	Work prohibited on: • Sundays • Public Holidays	No change	Play Pause	$0	○
1	8am-4pm	Work prohibited on: • Sundays • Public Holidays	Increase by 12 months	Play Pause	$50	○
2	9am-6pm	Work prohibited on: • Saturdays • Sundays • Public Holidays	Decrease by 6 months	Play Pause	$250	○

Photo: ST

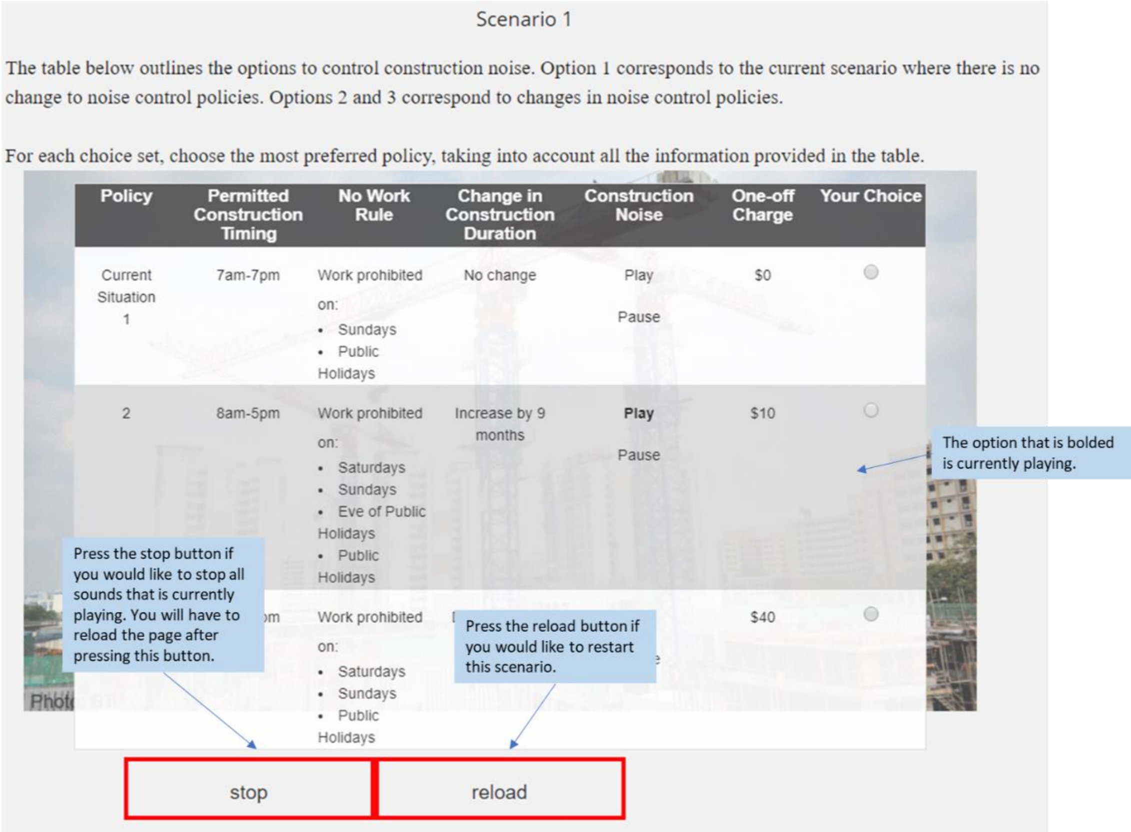
stop reload

Each column in the table outlines the measures to be implemented to control construction noise. The interpretation of the first option is shown below:



For each choice card, we will play the construction noises associated with each option before you can make your choice.
When the sound is playing, the option will be in grey and the 'Play' will be bolded.
After listening to all the sounds, you can replay any option by pressing 'Play'.

Please do not press next until you have finished listening to the noise clips.



Scenario 1

The table below outlines the options to control construction noise. Option 1 corresponds to the current scenario where there is no change to noise control policies. Options 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	One-off Charge	Your Choice
Current Situation 1	7am-7pm	Work prohibited on: • Sundays • Public Holidays	No change	Play Pause	$0	○
2	8am-5pm	Work prohibited on: • Saturdays • Sundays • Eve of Public Holidays • Public Holidays	Increase by 9 months	**Play** Pause	$10	○
[illegible]	[illegible]pm	Work prohibited on: • Saturdays • Sundays • Public Holidays	[illegible]	[illegible]	$40	○

stop | reload

How will these changes be funded?

Implementing these policies to reduce construction noise will cost money. For example, erection of noise barriers around construction sites will increase the cost of the construction. Different noise control policies will have different costs.

Compulsory annual payments to a government administered community fund will be used to pay for noise abatement of construction activity. You will only have to contribute to this fund when there is ongoing construction activity near your home. This policy will be implemented if at least 50% of residents agree to make this payment.

Keep in mind that these annual payments will reduce the amount of money you will need to spend to reduce the impact of construction noise in your home. For example, you may use less air-conditioning if construction activities are disallowed on weekends. Also, take into account your budget for other expenses when answering the questions.

Scenario 1:

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	7am-3pm	Work prohibited on: Sundays Public Holidays	Decrease by 12 months	Play Pause	S$100	70db
2	9am-6pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Increase by 6 months	Play Pause	S$200	60db

Scenario 2:

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	8am-6pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	Play Pause	S$250	60db
2	11am-3pm	Work prohibited on: Saturdays Sundays Public Holidays	Increase by 12 months	Play Pause	S$50	70db

Scenario 3:

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	11am-7pm	Work prohibited on: Saturdays Sundays Public Holidays	Decrease by 12 months	Play Pause	S$150	70db
2	8am-4pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Increase by 12 months	Play Pause	S$150	60db

Scenario 4:

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	9am-6pm	Work prohibited on: Sundays Public Holidays	Increase by 12 months	Play Pause	S$100	65db
2	7am-3pm	Work prohibited on: Saturdays Sundays Public Holidays	Decrease by 12 months	Play Pause	S$100	55db

Scenario 5:

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	7am-7pm	Work prohibited on: Saturdays Sundays Public Holidays	Increase by 6 months	Play Pause	S$50	55db
2	9am-4pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	Play Pause	S$250	65db

Scenario 6:

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	8am-4pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Increase by 12 months	Play Pause	S$150	65db
2	11am-7pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 12 months	Play Pause	S$100	55db

Scenario 7:

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	9am-4pm	Work prohibited on: Saturdays Sundays Public Holidays	Increase by 6 months	Play Pause	S$200	60db
2	7am-7pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	Play Pause	S$50	70db

<u>Scenario 8:</u>

Consider a construction site near your house. This site will take around three years to complete.
The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.
For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	Play Pause	S$0	75db
1	11am-3pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	Play Pause	S$50	55db
2	8am-6pm	Work prohibited on: Sundays Public Holidays	Increase by 6 months	Play Pause	S$150	65db

<u>Additional Questions:</u>

When answering the following questions, think about the information presented to you in the survey.

Did you understand all the information provided? [Single Answers]

1	I understood all provided information.
2	I understood most of the provided information.
3	I understood some of the provided information.
4	I did not understand the provided information.

Do you agree that the provided information was sufficient to make a choice? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

Do you agree that the proposed measures to control construction noise will be effective? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

Do you agree that your choices will have an impact on noise from construction activity? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

If you chose the current situation for all the previous 8 questions, what were your main reasons for <u>not</u> choosing a policy to reduce construction noise? [Multiple Answers]

1	Not applicable as I did not choose the current situation for all the previous 8 questions
2	I do not support the reduction of construction noise
3	The construction noise in the current location is not loud enough to adversely affect me
4	I support the reduction of construction noise, but I do not think that the policies to reduce construction noise will be effective
5	I support the reduction of construction noise, but the benefits of reduced construction noise is not worth the stated costs
6	I support the reduction of construction noise, but I cannot afford the additional expense
7	I support the reduction of construction noise, but I do not think I should be paying for it
8	I support the reduction of construction noise, but I do not think the funds will be effectively used to reduce construction noise
9	I found making a choice too confusing, so I always ticked the first box
10	Others, please specify: ___________________________________

SECTION 3: HEARING ACUITY TEST

In the following section of the questionnaire, we will measure the quietest sound you can hear. For each sound, there are two tests:

- Descending loudness. We will decrease the loudness of the sound from a clearly audible level. As soon as you stop hearing a sound, click on the box.
- Ascending loudness. We will increase the volume of the sound from an inaudible level. As soon as you hear a sound, no matter how faint the sound, click on the box.

Descending Hearing Test

Click on this box to start test

Click here to pause
or terminate the survey.

The sound is now playing and will gradually decrease in volume.
Click on this box when you do not hear a sound.

Click here to pause
or terminate the survey.

Ascending Hearing Test

Click on this box to start test

Click here to pause
or terminate the survey.

The sound is now playing and will gradually increase in volume.
Click on this box when you hear a sound.

Click here to pause
or terminate the survey.

SECTION 4: DEMOGRAPHIC PROFILE

Please be assured that the information provided in this section is for statistical analysis only and will be kept completely anonymous. You can choose not to respond to any question by leaving blank.

1. Gender

1	Male
2	Female
3	Prefer not to state

2. Race

1	Chinese
2	Malay
3	Indian
4	Eurasian
5	Others, please specify:
6	Prefer not to state

3. Type of dwelling

1	HDB (Studio Apartment, 1-Room or 2-Room
2	HDB (3-Room Flat)
3	HDB (4-Room Flat)
4	HDB (5-Room Flat or Executive Flat)
5	Condominium, Executive Condominium or other
6	Landed property
7	Others, please specify: ____________
8	Prefer not to state

4. What is your estimated gross monthly income from work? (This excludes employer's CPF contribution.)

1	Under S S$1,000
2	S S$1,000 – S S$1,999
3	S S$2,000 – S S$2,999
4	S S$3,000 – S S$3,999
5	S S$4,000 – S S$4,999
6	S S$5,000 – S S$5,999
7	S S$6,000 – S S$6,999
8	S S$7,000 – S S$7,999
9	S S$8,000 – S S$8,999
10	S S$9,000 – S S$9,999

11	S S$10,000 – S S$10,999
12	S S$11,000 – S S$11,999
13	S S$12,000 and over
14	Prefer not to state

5. Household Size

Number of people:______________

6. Are there any babies or toddlers aged younger than 5 years old in your household?

1	Yes
2	No
3	Prefer not to state

7. Are there any children aged between than 6 and 12 years old in your household?

1	Yes
2	No
3	Prefer not to state

8. What is your highest education qualification?

1	No formal qualification / Pre-primary / Lower primary (e.g. never attended school, kindergarten education or primary education without PSLE certificate)
2	Primary (e.g. PSLE certificate or equivalent)
3	Lower Secondary (e.g., Secondary education without a GCE 'O' / 'N' Level pass or their equivalent)
4	Secondary (e.g. GCE 'O' Level or 'N' Level certificate or equivalent)
5	Post-secondary – Non-tertiary: General & Vocational (e.g. GCE 'A' Level certificate, National ITE Certificate or equivalent)
6	Polytechnic Diploma
7	Professional Qualification and other Diploma (e.g. ITE diploma, NIE diploma, SIM diploma, LaSelle-SIA diploma, NAFA diploma or equivalent)
8	Bachelor's Degree or equivalent
9	Postgraduate Diploma / Certificate (excluding Master's and Doctorate)
10	Master's and Doctorate or equivalent
11	Others, please specify: ____________
12	Prefer not to state

9. Respondents' name: ____________________

10. Respondents' mobile number: ___________________

11. Respondents' mobile number: ___________________
12. Respondents' home number: ___________________

13. Respondents' office number: ___________________

14. Respondents' email: ___________________

15. Respondents' address: ___________________

The End

Please note that the annual payment proposed in this survey is a hypothetical scenario. There are currently no plans to implement any payment for noise reduction.

Please click Finish Button
Thank you for completing the survey!

Appendix 4: Text-based construction noise survey questionnaire

Introduction

Dear participant,

We are from Media Research Consultants and we are conducting a survey on behalf of the Singapore Government, in collaboration with the Australian National University (ANU). The survey will help us understand your views on construction noise in Singapore in order for us to propose policies to control construction noise.

Your participation in this survey is entirely voluntary and your responses and identity will be kept strictly confidential. The survey will take about 30 minutes. Thank you very much for your time.

Research Team

- Leong Chi Hoong, PhD Candidate, Australian National University,
  College of Asia and the Pacific, Crawford School of Public Policy
  chihoong.leong@anu.edu.au
- Jeff Bennett, Professor, Australian National University,
  College of Asia and the Pacific, Crawford School of Public Policy
  jeff.bennett@anu.edu.au

Participant information sheet

General Outline of the Project

- Description and methodology: Estimate the willingness-to-pay for a reduction in construction noise among residents in Singapore with a choice modelling survey.
- Participants: We will be surveying a representative sample of 1,000 individuals through a door-to-door survey.

Participant Involvement

- Voluntary participation and withdrawal: Your participation in this research is voluntary. You may decline to take part or to withdraw from the research without providing an explanation at any time until you have submitted the survey. As this survey is designed to be confidential you would not be able to withdraw your response upon submission of the completed survey questionnaire.
- What does participation in this survey entail?: You are invited to take part in a survey to ascertain the willingness-to-pay for a reduction in construction noise.
- Location and duration: The survey is being conducted at the doorstep of your home and will require approximately 30 minutes to complete.
- Remuneration: We will be providing an incentive of S$10 worth of NTUC vouchers for participation in this survey to compensate for your time to take part in this survey.
- Risks: You will have full control over whether you will like to proceed with the survey and you can terminate the survey at any point.
- Benefits: This project will provide us with an estimate of the benefits associated with the abatement of construction noise in Singapore, which would, in turn, enable us to propose policies to regulate construction noise.

Exclusion Criteria

- Participant limitation: You can only participate in this survey if you are a resident in Singapore and aged 18 or over.

Confidentiality

- Confidentiality: We will keep your identity confidential as far as allowed by law, unless you elect to be named within the research. Access to the data you provide will be restricted to the research team, and identifying details will be stored separately from the rest of the research data. Published results will only be reported in aggregate, and you will not be identifiable within published outputs unless you have elected otherwise.

Privacy Notice

- In collecting your personal information within this research, the ANU must comply with the Australia's Privacy Act 1988. The ANU Privacy Policy is available at https://policies.anu.edu.au/ppl/document/ANUP_010007and it contains information about how a person can: (i) Access or seek correction to their personal information; and (ii) Complain about a breach of an Australian Privacy Principle by ANU, and how ANU will handle the complaint.

Data Storage

- Where: Data will be securely stored on password protected computers at the Australian National University.
- Duration: All research data will be retained and securely stored for at least five years following publications arising from research. Data will have no identifying details attached.
- Handling of data following the required storage period: After the storage period, the data will be archived at the Crawford School of Public Policy for use in later research, including potentially by other researchers.

Queries and Concerns

Please feel free to contact us at the following email addresses if you have any other questions related to our survey:

1. Leong Chi Hoong, PhD Candidate, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy chihoong.leong@anu.edu.au, +65 9030 1763
2. Jeff Bennett, Professor, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy jeff.bennett@anu.edu.au

Contacts in Singapore: If you would like to contact an officer based in Singapore, please get in touch with:

3. Melinda Poh, Senior Assistant Director, Environmental Behavioural Sciences and Economics Research Unit melinda_poh@mewr.gov.sg
4. Royston Toh, Assistant Director, Environmental Behavioural Sciences and Economics Research Unit royston_toh@mewr.gov.sg

Ethics Committee Clearance

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol 2017/604). If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager

The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Consent for Participation

I have read and understood the Information Sheet you have given me about the research project, and I have had any questions and concerns about the project addressed to my satisfaction.

1. The list of concerns (if any) are as follows:
____

2. I agree to participate in the project

1	Agree	**CONTINUE**
2	Do not Agree	**TERMINATE**

3. I understand that, should I wish to, I can end the survey at any point.

1	Yes
2	No

SECTION 1: ABOUT YOU

1. Are you a Singapore resident (either Singapore citizen or permanent resident)?

1	Yes	**CONTINUE**
2	No	**TERMINATE**

2. What is your age?

1	Below 18 years old	**TERMINATE**
2	18-19 Years old	**<<Check Quota>>**
3	20-24 Years old	**<<Check Quota>>**
4	25-29 Years old	**<<Check Quota>>**
5	30-34 Years old	**<<Check Quota>>**
6	35-39 Years old	**<<Check Quota>>**
7	40-44 Years old	**<<Check Quota>>**
8	45-49 Years old	**<<Check Quota>>**
9	50-54 Years old	**<<Check Quota>>**
10	55-59 Years old	**<<Check Quota>>**
11	60-64 Years old	**<<Check Quota>>**

12	65-69 Years old	**<<Check Quota>>**
13	70 Years old and above	**<<Check Quota>>**

3. Have you ever been diagnosed with severe migraines by a medically-certified doctor?

1	Yes
2	No

4. Have you ever been diagnosed with tinnitus by a medically-certified doctor?

1	Yes
2	No

5. Do you have any existing hearing disorders?

1	Yes, please specify:___________________________________
2	No

<u>Experiences with Construction Noise</u>

1. Have you lived near a construction site before?

1	Yes
2	No

2. If you have lived near a construction site, how annoying was the construction noise experienced?

1	Not annoying at all
2	A bit annoying
3	Annoying
4	Very annoying
5	Exceedingly annoying
6	Not applicable, I have not lived near a construction

3. If you were staying near a construction site causing this level of noise, how would you reduce the impact of the noise? [Multiple Answers]

1	Install sound-proof, double glazed windows.
2	Close windows when construction noise is loud.
3	Close window and switch on air-conditioning when construction noise is loud.
4	Use of ear plugs.
5	Leave house to avoid construction noise.

6	Do not undertake any measures.
7	Others, please specify: ___________________________________

4. How much have you previously spent on these measures to reduce the impact of construction noise?

Amount of Money Spent SGD:_______

SECTION 2: CONSTRUCTION NOISE IN SINGAPORE

Singapore is geographically small, highly urbanised and densely populated. The rapid pace of development has led to a high number of construction sites in Singapore. However, residents living near construction sites may be affected by higher levels of noise.

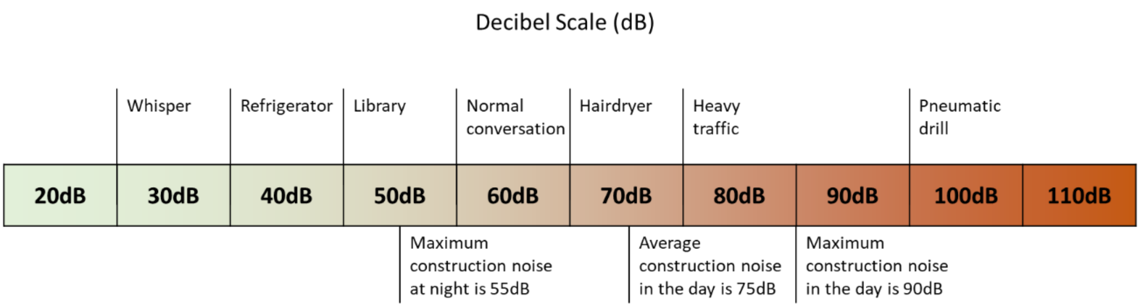
In this section of the survey, we will like to find out how much you are willing to pay for a reduction in construction noise. Your responses to this section are important. Survey results will inform policies that the Government can implement to control construction noise.

Loudness of Construction Noise

Consider a construction site near your house. This site will take around three years to complete. When construction is ongoing, noise levels at your house will be higher.

Loudness of noise is described in decibels. A 10dB increase in noise levels approximately corresponds to a doubling of perceived loudness.

Examples of the loudness of some sounds described in decibels are shown below.



As can be seen, noise from construction sites are currently regulated to be below 75dB averaged over a 12hr interval as measured from the nearest house in the day. This is louder than normal conversation at home.

Mitigation Measures:

What can be done to reduce construction noise?
The next section of the survey seeks to understand your preferences to reduce construction noise in Singapore.

Noise from construction sites are currently regulated to be below 75dB averaged over a 12hr interval as measured from the nearest house. In order to further reduce the impact of construction noise, the following policies could be implemented.

1) Regulate construction equipment and practices in order to encourage construction companies to emit lower levels of noise.
2) Reduce the noise emitted from construction sites with noise barriers.
3) Retrofit windows with sound-proof double-glazed windows.
4) Disallow or restrict construction activities at nights and on weekends as well as public holidays.

These policies could change the following factors:
1) **Loudness of construction noise**: different policies could result in different noise levels.
2) **Time when construction activity starts and ends**: construction activity could start later in the morning or end earlier in the evenings.
3) **Days when construction activity is prohibited**: construction activities could be prohibited on Sundays only or on both Saturday and Sunday.
4) **Length of construction activity**: more construction work could be carried out at the same time – leading to higher levels of noise, but shorter construction duration.
5) **Annual payment**: these changes will have different costs, funded by a compulsory annual payment to a community fund, which is administered by the government. You will only have to contribute to the fund when there is ongoing construction activity.

Choice Card Layout

In the following eight scenarios, we would like to ask you to choose between three different options. Each option will outline different methods to control noise from the construction site near your house, leading to different experiences.

In the first row, we present the current situation, where no additional measures to control construction noise is implemented.
In the second and third rows, we present possible changes to policies to reduce construction noise.

Each column in the table outlines the measures to be implemented to control construction noise.

As an example, the interpretation of the Option 2 of a choice card is shown below:

Scenario 1:

Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Construction Noise	Annual Payment
Current Situation	7am-7pm	Work prohibited on: • Sundays • Public Holidays	No change	75db	$0
1	7am-3pm	Work prohibited on: • Sundays • Public Holidays	Decrease by 12 months	70db	$100
2	9am-6pm	Work prohibited on: • Saturdays • Sundays • Public Holidays	Increase by 6 months	60db	$200

Construction can only occur between 9am and 6pm

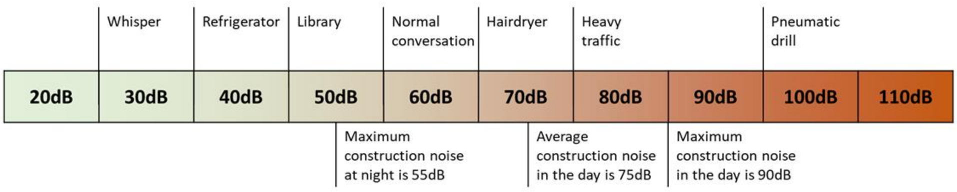
Construction is not allowed on Saturdays, Sundays and Public Holidays

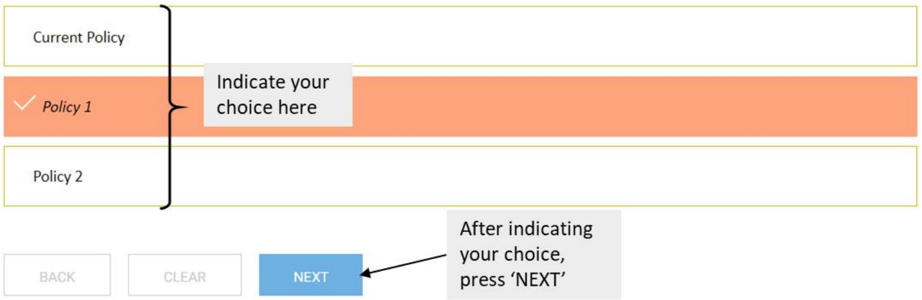
Duration of construction activity is increased by 6 months

Noise at your house during the construction is 60dB

Annual payment associated with Option 2

Decibel Scale (dB)





How will these changes be funded?

Implementing these policies to reduce construction noise will cost money. For example, erection of noise barriers around construction sites will increase the cost of the construction. Different noise control policies will have different costs.

Compulsory annual payments to a government administered community fund will be used to pay for noise abatement of construction activity. You will only have to contribute to this fund when there is ongoing construction activity near your home. This policy will be implemented if at least 50% of residents agree to make this payment.

Keep in mind that these annual payments will reduce the amount of money you will need to spend to reduce the impact of construction noise in your home. For example, you may use less air-conditioning if construction activities are disallowed on weekends. Also, take into account your budget for other expenses when answering the questions.

<u>Scenario 1:</u>

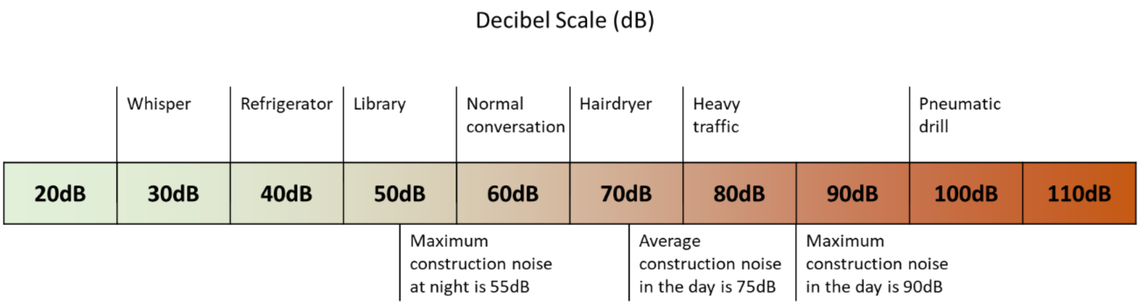
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	**Permitted Construction Timing**	**No Work Rule**	**Change in Construction Duration**	**Annual Payment**	**Noise level**
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	7am-3pm	Work prohibited on: Sundays Public Holidays	Decrease by 12 months	S$100	70db
2	9am-6pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Increase by 6 months	S$200	60db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Scenario 2:

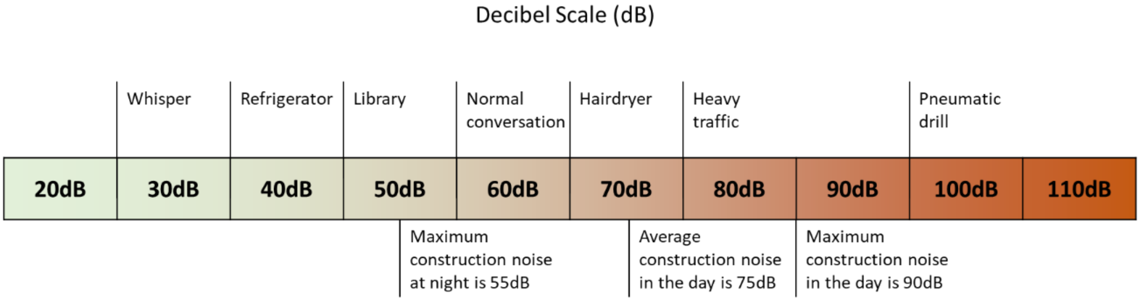
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	8am-6pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	S$250	60db
2	11am-3pm	Work prohibited on: Saturdays Sundays Public Holidays	Increase by 12 months	S$50	70db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Scenario 3:

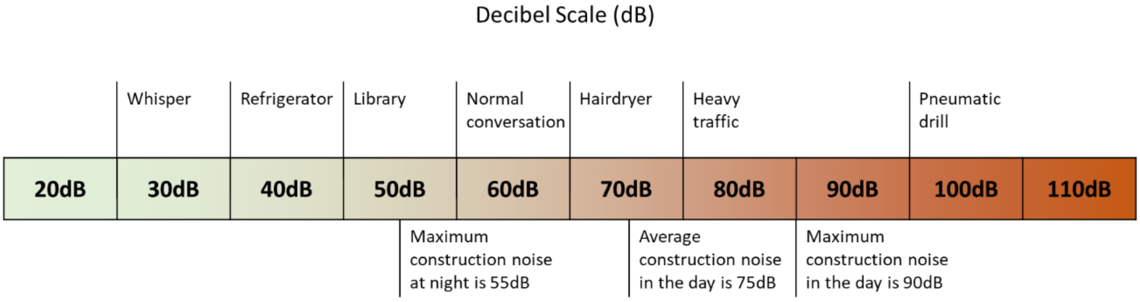
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	11am-7pm	Work prohibited on: Saturdays Sundays Public Holidays	Decrease by 12 months	S$150	70db
2	8am-4pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Increase by 12 months	S$150	60db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Scenario 4:

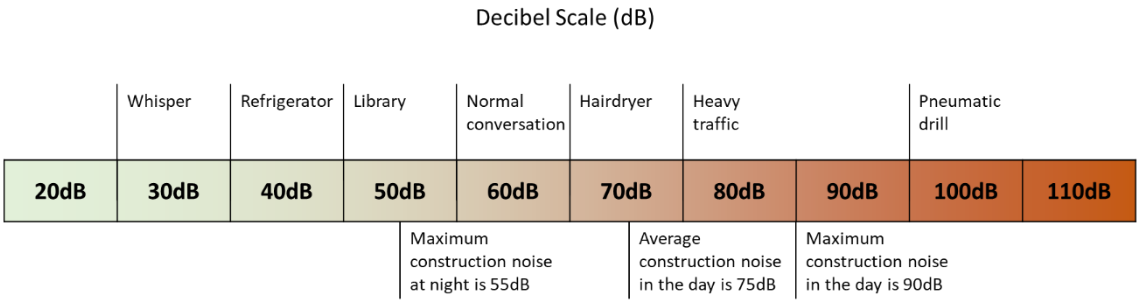
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	9am-6pm	Work prohibited on: Sundays Public Holidays	Increase by 12 months	S$100	65db
2	7am-3pm	Work prohibited on: Saturdays Sundays Public Holidays	Decrease by 12 months	S$100	55db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Scenario 5:

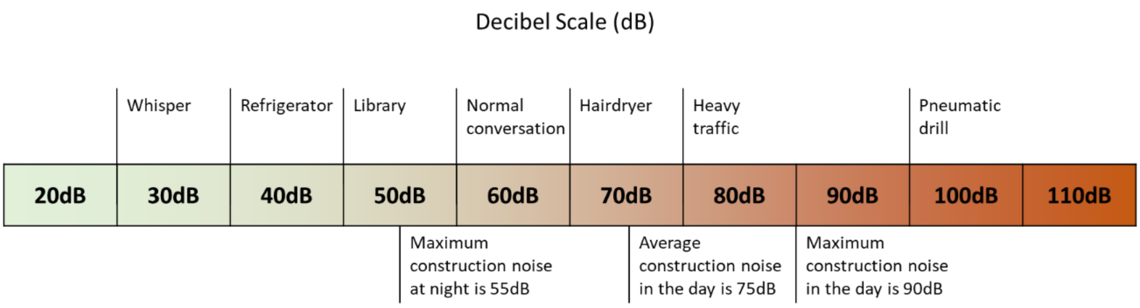
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	7am-7pm	Work prohibited on: Saturdays Sundays Public Holidays	Increase by 6 months	S$50	55db
2	9am-4pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	S$250	65db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Scenario 6:

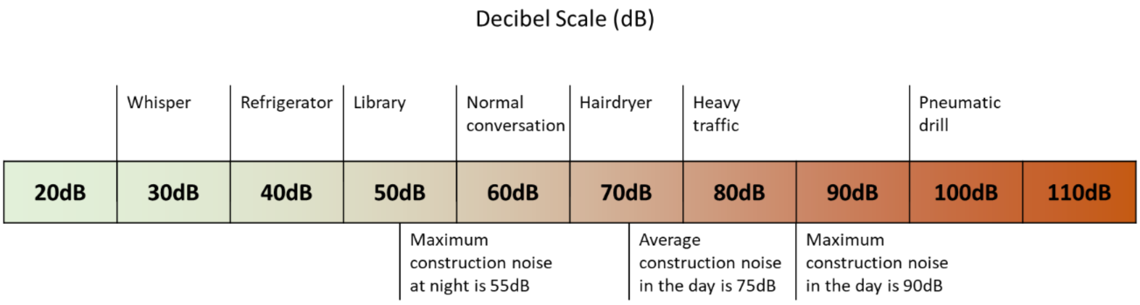
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	8am-4pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Increase by 12 months	S$150	65db
2	11am-7pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 12 months	S$100	55db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Scenario 7:

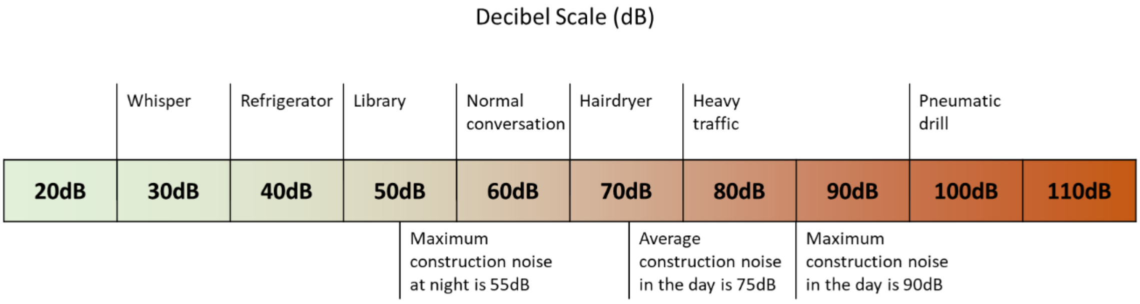
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	9am-4pm	Work prohibited on: Saturdays Sundays Public Holidays	Increase by 6 months	S$200	60db
2	7am-7pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	S$50	70db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Scenario 8:

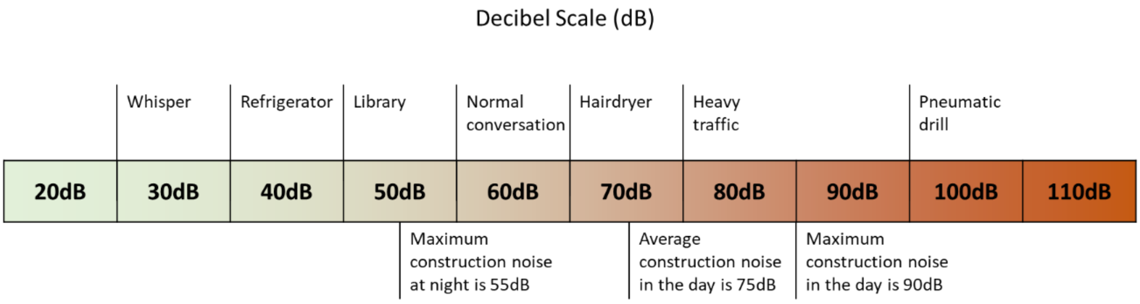
Consider a construction site near your house. This site will take around three years to complete.

The table below outlines the options to control noise from this construction site. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Permitted Construction Timing	No Work Rule	Change in Construction Duration	Annual Payment	Noise level
Current Situation	7am-7pm	Work prohibited on: Sundays Public Holidays	No change	S$0	75db
1	11am-3pm	Work prohibited on: Saturdays Sundays Eve of Public Holidays Public Holidays	Decrease by 6 months	S$50	55db
2	8am-6pm	Work prohibited on: Sundays Public Holidays	Increase by 6 months	S$150	65db

Recall that a 10dB increase in construction noise levels approximately corresponds with a doubling of perceived loudness. For reference, the decibel scale is:



Additional Question:

When answering the following questions, think about the information presented to you in the survey.

Did you understand all the information provided? [Single Answers]

1	I understood all provided information.
2	I understood most of the provided information.
3	I understood some of the provided information.
4	I did not understand the provided information.

Do you agree that the provided information was sufficient to make a choice? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

Do you agree that the proposed measures to control construction noise will be effective? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

Do you agree that your choices will have an impact on noise from construction activity? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

When answering the questions, were you able to imagine the loudness of the construction noise in the proposed changes? [Single Answers]

1	I could imagine the loudness of all the noises in the
2	I had a good idea of most of the noise.
3	I had some idea of the described noise levels.
4	I could not imagine any of the described noise levels.

Would any of the following additional information have helped you make a more informed decision? [Single Answers for each row]

	Very useful	Useful	Fairly useful	Not useful
Hearing the noise recordings at different volumes instead of description of the decibel				
More comparisons on the decibel scale				
More information on the effects of construction noise on human health				
More details on the policies to reduce construction noise				

Do you have any suggestions for other information? [text]

Please answer the following questions about the decibel scale: [Single Answers for each row]

	True	False
The average loudness of a conversation is 60dB		
Singapore’s average daytime construction noise is around 75dB		
A sound that is 100dB is perceived to be twice as loud as a noise that is 50dB		
The decibel is measured on the logarithmic scale		

If you chose the current situation for all the previous 8 questions, what were your main reasons for not choosing a policy to reduce construction noise? [Multiple Answers]

1	Not applicable as I did not choose the current situation for all the previous 8 questions
2	I do not support the reduction of construction noise
3	The construction noise in the current location is not loud enough to adversely affect me

4	I support the reduction of construction noise, but I do not think that the policies to reduce construction noise will be effective
5	I support the reduction of construction noise, but the benefits of reduced construction noise is not worth the stated costs
6	I support the reduction of construction noise, but I cannot afford the additional expense
7	I support the reduction of construction noise, but I do not think I should be paying for it
8	I support the reduction of construction noise, but I do not think the funds will be effectively used to reduce construction noise
9	I found making a choice too confusing, so I always ticked the first box
10	Others, please specify: ____________________________________

SECTION 3: DEMOGRAPHIC PROFILE

Please be assured that the information provided in this section is for statistical analysis only and will be kept completely anonymous. You can choose not to respond to any question by leaving blank.

1. Gender

1	Male
2	Female
3	Prefer not to state

2. Race

1	Chinese
2	Malay
3	Indian
4	Eurasian
5	Others, please specify:
6	Prefer not to state

3. Type of dwelling

1	HDB (Studio Apartment, 1-Room or 2-Room
2	HDB (3-Room Flat)
3	HDB (4-Room Flat)
4	HDB (5-Room Flat or Executive Flat)
5	Condominium, Executive Condominium or other
6	Landed property
7	Others, please specify: ____________
8	Prefer not to state

4. What is your estimated gross monthly income from work? (This excludes employer's CPF contribution.)

1	Under S S$1,000
2	S S$1,000 – S S$1,999
3	S S$2,000 – S S$2,999
4	S S$3,000 – S S$3,999
5	S S$4,000 – S S$4,999
6	S S$5,000 – S S$5,999
7	S S$6,000 – S S$6,999
8	S S$7,000 – S S$7,999
9	S S$8,000 – S S$8,999
10	S S$9,000 – S S$9,999

11	S S$10,000 – S S$10,999
12	S S$11,000 – S S$11,999
13	S S$12,000 and over
14	Prefer not to state

5. Household Size

Number of people:______________

6. Are there any babies or toddlers aged younger than 5 years old in your household?

1	Yes
2	No
3	Prefer not to state

7. Are there any children aged between than 6 and 12 years old in your household?

1	Yes
2	No
3	Prefer not to state

8. What is your highest education qualification?

1	No formal qualification / Pre-primary / Lower primary (e.g. never attended school, kindergarten education or primary education without PSLE certificate)
2	Primary (e.g. PSLE certificate or equivalent)
3	Lower Secondary (e.g., Secondary education without a GCE 'O' / 'N' Level pass or their equivalent)
4	Secondary (e.g. GCE 'O' Level or 'N' Level certificate or equivalent)
5	Post-secondary – Non-tertiary: General & Vocational (e.g. GCE 'A' Level certificate, National ITE Certificate or equivalent)
6	Polytechnic Diploma
7	Professional Qualification and other Diploma (e.g. ITE diploma, NIE diploma, SIM diploma, LaSelle-SIA diploma, NAFA diploma or equivalent)
8	Bachelor's Degree or equivalent
9	Postgraduate Diploma / Certificate (excluding Master's and Doctorate)
10	Master's and Doctorate or equivalent
11	Others, please specify: ____________
12	Prefer not to state

9. Respondents' name: ____________________

10. Respondents' mobile number: ___________________

11. Respondents' mobile number: ___________________
12. Respondents' home number: ___________________

13. Respondents' office number: ___________________

14. Respondents' email: ___________________

15. Respondents' address: ___________________

The End

Please note that the annual payment proposed in this survey is a hypothetical scenario. There are currently no plans to implement any payment for noise reduction.

Please click Finish Button
Thank you for completing the survey!

Appendix 5: Audio-based road noise survey questionnaire

Introduction

Dear participant,

We are from Media Research Consultants and we are conducting a survey on behalf of the Singapore Government, in collaboration with the Australian National University (ANU). The survey will help us understand your views on construction noise in Singapore in order for us to propose policies to control road noise.

Your participation in this survey is entirely voluntary and your responses and identity will be kept strictly confidential. The survey will take about 30 minutes. Thank you very much for your time.

Research Team

- Leong Chi Hoong, PhD Candidate, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy chihoong.leong@anu.edu.au
- Jeff Bennett, Professor, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy jeff.bennett@anu.edu.au

Participant information sheet

General Outline of the Project

- *Description and methodology*: Estimate the willingness-to-pay for a reduction in road noise among residents in Singapore with a choice modelling survey.
- *Participants*: We will be surveying a representative sample of 500 individuals through a door-to-door survey.

Participant Involvement

- Voluntary participation and withdrawal: Your participation in this research is voluntary. You may decline to take part or to withdraw from the research without providing an explanation at any time until you have submitted the survey. As this survey is designed to be confidential you would not be able to withdraw your response upon submission of the completed survey questionnaire.
- What does participation in this survey entail?: You are invited to take part in a survey to ascertain the willingness-to-pay for a reduction in road noise. The survey questionnaire consists of three main sections: (i) a series of questions where you choose between different types of road noises and associated costs; (ii) a hearing acuity test to understand your sensitivity to sounds; and (iii) a demography section to understand your background.
- Location and duration: The survey is being conducted at the doorstep of your home and will require approximately 30 minutes to complete.
- Remuneration: We will be providing an incentive of S$10 worth of NTUC vouchers for participation in this survey to compensate for your time to take part in this survey.
- Risks: You will have full control over whether you will like to proceed with the survey and you can terminate the survey at any point. If, for any reason, you will like to stop participation, a save button is provided for you to stop participation immediately.

- Benefits: This project will provide us with an estimate of the benefits associated with the abatement of road noise in Singapore, which would, in turn, enable us to propose policies to regulate road noise.

Exclusion Criteria

- Participant limitation: You can only participate in this survey if you are a resident in Singapore and aged 18 or over.

Confidentiality

- Confidentiality: We will keep your identity confidential as far as allowed by law, unless you elect to be named within the research. Access to the data you provide will be restricted to the research team, and identifying details will be stored separately from the rest of the research data. Published results will only be reported in aggregate, and you will not be identifiable within published outputs unless you have elected otherwise.

Privacy Notice

- In collecting your personal information within this research, the ANU must comply with the Privacy Act 1988. The ANU Privacy Policy is available at https://policies.anu.edu.au/ppl/document/ANUP_010007and it contains information about how a person can: (i) Access or seek correction to their personal information; and (ii) Complain about a breach of an Australian Privacy Principle by ANU, and how ANU will handle the complaint.

Data Storage

- Where: Data will be securely stored on password protected computers at the Australian National University.
- Duration: All research data will be retained and securely stored for at least five years following publications arising from research. Data will have no identifying details attached.
- Handling of data following the required storage period: After the storage period, the data will be archived at the Crawford School of Public Policy for use in later research, including potentially by other researchers.

Queries and Concerns

Please feel free to contact us at the following email addresses if you have any other questions related to our survey:

1. Leong Chi Hoong, PhD Candidate, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy chihoong.leong@anu.edu.au, +65 9030 1763
2. Jeff Bennett, Professor, Australian National University, College of Asia and the Pacific, Crawford School of Public Policy jeff.bennett@anu.edu.au

Contacts in Singapore: If you would like to contact an officer based in Singapore, please get in touch with:
3. Liu Qiaozhen, Civil Engineer, Commuter and Road Infrastructure, liu_qiaozhen@lta.gov.sg

Ethics Committee Clearance

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol 2017/604). If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Consent for Participation

I have read and understood the Information Sheet you have given me about the research project, and I have had any questions and concerns about the project addressed to my satisfaction.

1. The list of concerns (if any) are as follows:
____

2. I agree to participate in the project

1	Agree	**CONTINUE**
2	Do not Agree	**TERMINATE**

3. I understand that, should I wish to, I can end the survey at any point.

1	Yes
2	No

About this Survey

This survey is about construction noise in Singapore and consists of four parts:

- **Part 1: About you.** We ask a few questions about you.
- **Part 2: Your choices.** We ask you to choose between different types of construction noise.
- **Part 3: Hearing acuity test.** We will play several sounds to understand your sensitivity to sounds.
- **Part 4: About you.** We ask a few more questions about you.

SECTION 1: ABOUT YOU

1. Are you a Singapore resident (either Singapore citizen or permanent resident)?

1	Yes	**CONTINUE**
2	No	**TERMINATE**

2. What is your age?

1	Below 18 years old	**TERMINATE**
2	18-19 Years old	**<<Check Quota>>**
3	20-24 Years old	**<<Check Quota>>**
4	25-29 Years old	**<<Check Quota>>**
5	30-34 Years old	**<<Check Quota>>**
6	35-39 Years old	**<<Check Quota>>**
7	40-44 Years old	**<<Check Quota>>**
8	45-49 Years old	**<<Check Quota>>**
9	50-54 Years old	**<<Check Quota>>**
10	55-59 Years old	**<<Check Quota>>**
11	60-64 Years old	**<<Check Quota>>**
12	65-69 Years old	**<<Check Quota>>**
13	70 Years old and above	**<<Check Quota>>**

3. Have you lived near a major road or expressway before?

1	Yes
2	No

4. If you have lived near a major road or expressway, how annoying was the noise experienced?

1	Not annoying at all
2	A bit annoying
3	Annoying
4	Very annoying
5	Exceedingly annoying
6	Not applicable, I have not lived near a construction

5. Have you ever been diagnosed with severe migraines by a medically-certified doctor?

1	Yes
2	No

6. Have you ever been diagnosed with tinnitus by a medically-certified doctor?

1	Yes
2	No

7. Do you have any existing hearing disorders?

1	Yes, please specify:__________________________________
2	No

SECTION 2: CONSTRUCTION NOISE IN SINGAPORE

In order to ensure that everyone in Singapore can conveniently travel to other parts of Singapore, the Government has built a network of roads and expressways. However, residents living near these roads may experience higher levels of noise.

In this section of the survey, we will like to find out how much you are willing to pay for a reduction in noise from major roads and expressways. Your responses to this section are important. Survey results will inform policies that the Government can implement to control road noise.

Demonstration

In order to illustrate the noise generated by major roads and expressways, we will first play a 10-second recording of road noise in Singapore.

If you would like to raise any concerns when we are playing the noise, please pause the survey and inform the surveyor.

Press this box to start

You can proceed to the next page after the sound clip has ended.

Perception of Road Noise

1. Was the recorded road noise you just heard similar to actual road noise that you typically encounter?

1	Yes
2	No
3	Not applicable as I have not encountered road noise before

2. How annoying was the construction noise you just heard?

1	Not annoying at all
2	A bit annoying
3	Annoying
4	Very annoying
5	Exceedingly annoying

3. If you were staying near a major road or expressway causing this level of noise, how would you reduce the impact of the noise? (You can specify more than one option.)

1	Install sound-proof, double glazed windows.
2	Close windows when road noise is loud.
3	Close window and switch on air-conditioning when road noise is loud.
4	Use of ear plugs.
5	Leave house to avoid road noise.
6	Do not undertake any measures.
7	Others, please specify: ___________________________________

4. How much have you previously spent on these measures to reduce the impact of road noise?

Amount of Money Spent SGD:________

5. Which of the following road noise is sufficiently quiet such that you will not be willing to pay for further noise reduction? (Please press on the play button to hear the sound clips.)

1	Sound Clip 1
2	Sound Clip 2
3	Sound Clip 3
4	Sound Clip 4
5	Sound Clip 5
6	None of the above as I am willing to pay even if the sound is as quiet as sound clip 5
7	None of the above as I am not willing to pay even if the sound is as loud as sound clip 1

Mitigation Measures:

What can be done to reduce road noise?

The next section of the survey seeks to understand your preferences to reduce road noise in Singapore.

In order to reduce the impact of road noise, the following policies could be implemented.

1) Tighten regulations for noise emissions from vehicles.
2) Reduce the noise emitted from major roads and expressways with noise barriers.
3) Construct roads with low-noise pavement material.
4) Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.

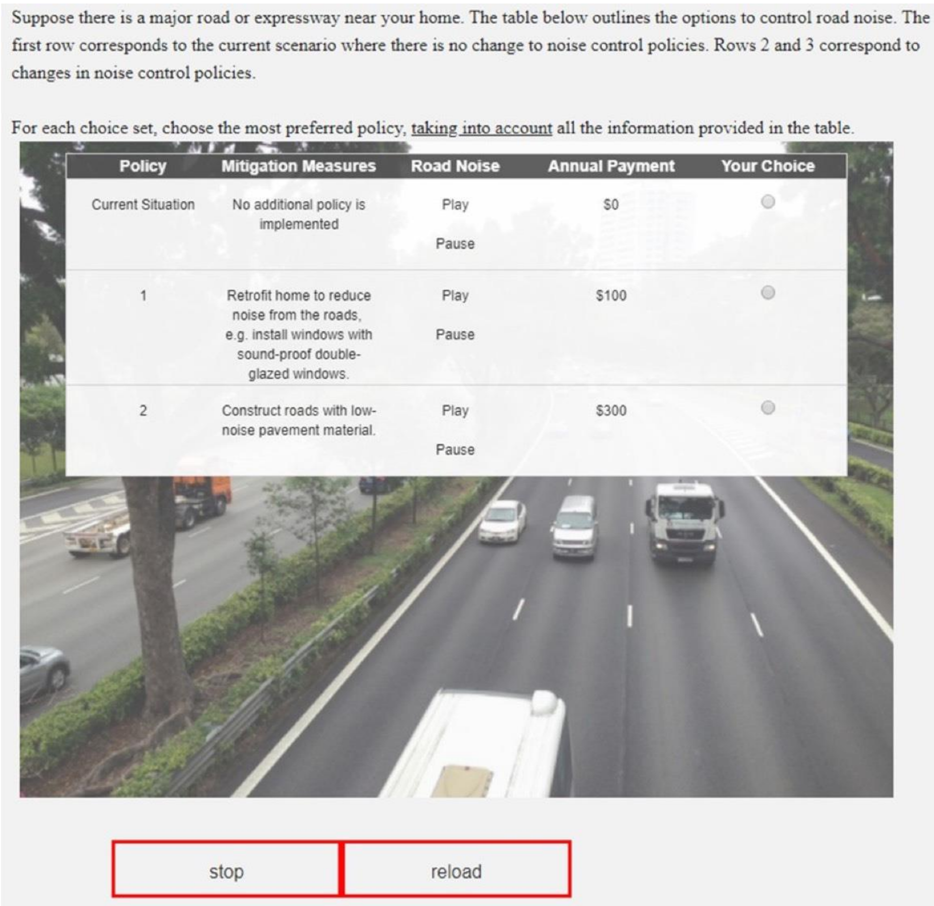
These policies could change the following factors:

1) **Method to control road noise**: different policies, e.g., road noise barriers, more space between roads and residences, changing the surface of the road or sound proofing of homes, could result in different noise levels.
2) **Loudness of road noise**: different policies could result in different noise levels.
3) **Annual payment**: these policies will have different costs, funded by a compulsory annual payment to a community fund, which is administered by the government.

Choice Card Layout:

Suppose there is a major road or expressway near your home. In the following eight questions, we would like to ask you to choose between three different options. Each option will outline different methods to control road noise, leading to different experiences.

In the first row, we present the current situation where there is no change to noise control policies.
In the second and third rows, we present the reduced noise levels by the possible noise mitigation measures.
An example of a question is shown below:

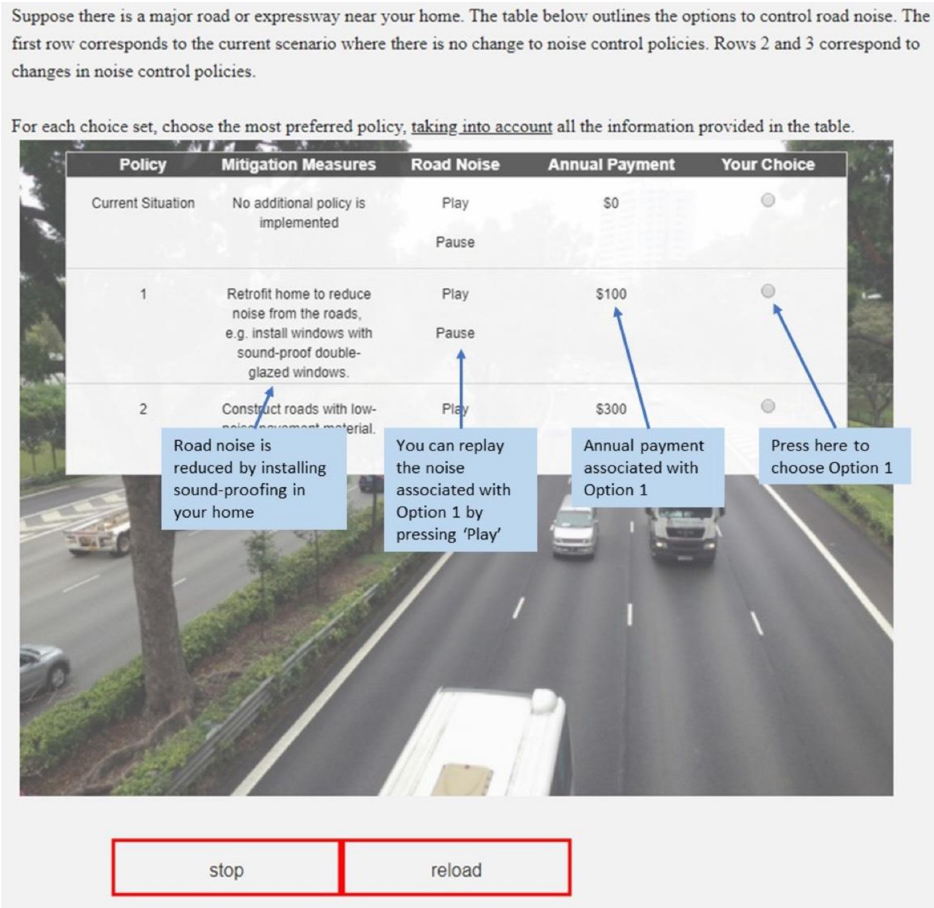

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation Measures	Road Noise	Annual Payment	Your Choice
Current Situation	No additional policy is implemented	Play Pause	$0	○
1	Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.	Play Pause	$100	○
2	Construct roads with low-noise pavement material.	Play Pause	$300	○

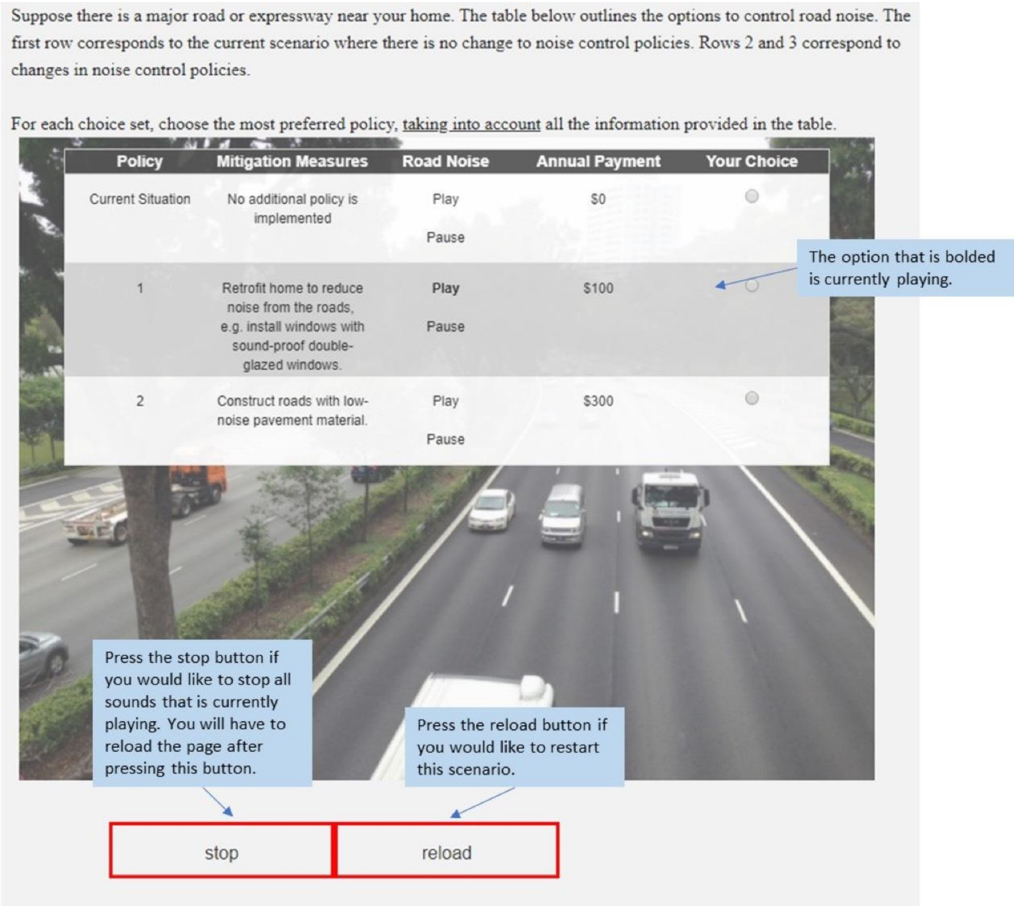
stop reload

Each column in the table outlines the measures to be implemented to control road noise. The interpretation of the first option is shown below:



For each choice card, we will play the road noises associated with each option before you can make your choice.
When the sound is playing, the option will be in grey and the 'Play' will be bolded.
After listening to all the sounds, you can replay any option by pressing 'Play'.

Please <u>do not</u> press next until you have finished listening to the noise clips.


Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation Measures	Road Noise	Annual Payment	Your Choice
Current Situation	No additional policy is implemented	Play Pause	$0	
1	Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.	**Play** Pause	$100	
2	Construct roads with low-noise pavement material.	Play Pause	$300	

How will these changes be funded?

Implementing these policies to reduce road noise will cost money. For example, the erection of noise barriers near major roads and expressways would increase the cost of construction. Different noise control policies will have different costs. This policy will be implemented if at least 50% of residents agree to make this payment.

These noise control measures will be paid for by an annual compulsory payment to a community fund, which is administered by the government.

Keep in mind that these additional charges will reduce the amount of money you will need to pay to reduce the impact of road noise in your home. For example, you may use less air-conditioning if noise barriers were installed to reduce road noise. Also, take into account your budget for other expenses when answering the questions.

Scenario 1:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.	Play Pause	S$300	55db
2	Tighten regulations for noise emissions from vehicles.	Play Pause	S$300	60db

Scenario 2:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Reduce the noise emitted from major roads and expressways with noise barriers.	Play Pause	S$100	70db
2	Reduce the noise emitted from major roads and expressways with noise barriers.	Play Pause	S$200	60db

Scenario 3:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Construct roads with low-noise pavement material.	Play Pause	S$200	70db
2	Tighten regulations for noise emissions from vehicles.	Play Pause	S$500	70db

Scenario 4:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Tighten regulations for noise emissions from vehicles.	Play Pause	S$200	60db
2	Reduce the noise emitted from major roads and expressways with noise barriers.	Play Pause	S$100	70db

Scenario 5:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Reduce the noise emitted from major roads and expressways with noise barriers.	Play Pause	S$400	65db
2	Tighten regulations for noise emissions from vehicles.	Play Pause	S$100	65db

Scenario 6:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Construct roads with low-noise pavement material.	Play Pause	S$100	55db
2	Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.	Play Pause	S$300	55db

Scenario 7:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Tighten regulations for noise emissions from vehicles.	Play Pause	S$300	60db
2	Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.	Play Pause	S$400	65db

Scenario 8:

Suppose there is a major road or expressway near your home. The table below outlines the options to control road noise. The first row corresponds to the current scenario where there is no change to noise control policies. Rows 2 and 3 correspond to changes in noise control policies.

For each choice set, choose the most preferred policy, taking into account all the information provided in the table.

Policy	Mitigation measure	Construction Noise	Annual Payment	Noise level
Current Situation	No additional policy is implemented.	Play Pause	S$0	75db
1	Retrofit home to reduce noise from the roads, e.g. install windows with sound-proof double-glazed windows.	Play Pause	S$500	65db
2	Construct roads with low-noise pavement material.	Play Pause	S$200	55db

Additional Questions:

When answering the following questions, think about the information presented to you in the survey.

Did you understand all the information provided? [Single Answers]

1	I understood all provided information.
2	I understood most of the provided information.
3	I understood some of the provided information.
4	I did not understand the provided information.

Do you agree that the provided information was sufficient to make a choice? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

Do you agree that the proposed measures to control construction noise will be effective? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

Do you agree that your choices will have an impact on noise from construction activity? [Single Answers]

1	Strongly agree.
2	Agree.
3	Disagree.
4	Strongly disagree.

If you chose the current situation for all the previous 8 questions, what were your main reasons for <u>not</u> choosing a policy to reduce road noise? [Multiple Answers]

1	Not applicable as I did not choose the current situation for all the previous 8 questions
2	I do not support the reduction of road noise
3	The road noise in the current location is not loud enough to adversely affect me
4	I support the reduction of road noise, but I do not think that the policies to reduce road noise will be effective
5	I support the reduction of road noise, but the benefits of reduced road noise is not worth the stated costs
6	I support the reduction of road noise, but I cannot afford the additional expense
7	I support the reduction of road noise, but I do not think I should be paying for it
8	I support the reduction of road noise, but I do not think the funds will be effectively used to reduce road noise
9	I found making a choice too confusing, so I always ticked the first box
10	Others, please specify: ________________________________

SECTION 3: HEARING ACUITY TEST

In the following section of the questionnaire, we will measure the quietest sound you can hear. For each sound, there are two tests:

- Descending loudness. We will decrease the loudness of the sound from a clearly audible level. As soon as you stop hearing a sound, click on the box.
- Ascending loudness. We will increase the volume of the sound from an inaudible level. As soon as you hear a sound, no matter how faint the sound, click on the box.

Descending Hearing Test

Click on this box to start test

Click here to pause
or terminate the survey.

The sound is now playing and will gradually decrease in volume.
Click on this box when you do not hear a sound.

Click here to pause
or terminate the survey.

Ascending Hearing Test

Click on this box to start test

Click here to pause
or terminate the survey.

The sound is now playing and will gradually increase in volume.
Click on this box when you hear a sound.

Click here to pause
or terminate the survey.

SECTION 4: DEMOGRAPHIC PROFILE

Please be assured that the information provided in this section is for statistical analysis only and will be kept completely anonymous. You can choose not to respond to any question by leaving blank.

1. Gender

1	Male
2	Female
3	Prefer not to state

2. Race

1	Chinese
2	Malay
3	Indian
4	Eurasian
5	Others, please specify:
6	Prefer not to state

3. Type of dwelling

1	HDB (Studio Apartment, 1-Room or 2-Room
2	HDB (3-Room Flat)
3	HDB (4-Room Flat)
4	HDB (5-Room Flat or Executive Flat)
5	Condominium, Executive Condominium or other
6	Landed property
7	Others, please specify: ____________
8	Prefer not to state

4. What is your estimated gross monthly income from work? (This excludes employer's CPF contribution.)

1	Under S S$1,000
2	S S$1,000 – S S$1,999
3	S S$2,000 – S S$2,999
4	S S$3,000 – S S$3,999
5	S S$4,000 – S S$4,999
6	S S$5,000 – S S$5,999
7	S S$6,000 – S S$6,999
8	S S$7,000 – S S$7,999
9	S S$8,000 – S S$8,999
10	S S$9,000 – S S$9,999

11	S S$10,000 – S S$10,999
12	S S$11,000 – S S$11,999
13	S S$12,000 and over
14	Prefer not to state

5. Household Size

Number of people:______________

6. Are there any babies or toddlers aged younger than 5 years old in your household?

1	Yes
2	No
3	Prefer not to state

7. Are there any children aged between than 6 and 12 years old in your household?

1	Yes
2	No
3	Prefer not to state

8. What is your highest education qualification?

1	No formal qualification / Pre-primary / Lower primary (e.g. never attended school, kindergarten education or primary education without PSLE certificate)
2	Primary (e.g. PSLE certificate or equivalent)
3	Lower Secondary (e.g., Secondary education without a GCE 'O' / 'N' Level pass or their equivalent)
4	Secondary (e.g. GCE 'O' Level or 'N' Level certificate or equivalent)
5	Post-secondary – Non-tertiary: General & Vocational (e.g. GCE 'A' Level certificate, National ITE Certificate or equivalent)
6	Polytechnic Diploma
7	Professional Qualification and other Diploma (e.g. ITE diploma, NIE diploma, SIM diploma, LaSelle-SIA diploma, NAFA diploma or equivalent)
8	Bachelor's Degree or equivalent
9	Postgraduate Diploma / Certificate (excluding Master's and Doctorate)
10	Master's and Doctorate or equivalent
11	Others, please specify: ____________
12	Prefer not to state

9. Respondents' name: ____________________

10. Respondents' mobile number: ____________________

11. Respondents' mobile number: ____________________
12. Respondents' home number: ____________________

13. Respondents' office number: ____________________

14. Respondents' email: ____________________

15. Respondents' address: ____________________

The End

Please note that the annual payment proposed in this survey is a hypothetical scenario. There are currently no plans to implement any payment for noise reduction.

Please click Finish Button
Thank you for completing the survey!