The Hong Kong Polytechnic University

Department of Building Services Engineering

Perception of Noise Annoyance

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A thesis submitted in partial fulfillment of the requirements

for the degree of Doctor of Philosophy

October 2011

CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement had been made in the text.

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ABSTRACT

Abstract of thesis entitled: Perception of Noise Annoyance

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Annoyance has long been recognized as a major noise impact which impairs individuals' well-being. Many noise mitigation measures have been proposed to alleviate the problem of noise annoyance. However, the factors influencing noise annoyance perception and their impacts on annoyance perception have not been fully investigated. Also, there are still some knowledge gaps in relation to annoyance perception which should be resolved for facilitating better decision making. Hitherto, there is no protocol available for estimating the monetary benefit gains arising from reduced annoyance in a probabilistic manner. Also, it is unclear whether the annoyance prediction model can be applied to a mixed noise situation, e.g. in the presence of both human and road noise, which is quite common in Hong Kong. Accordingly, this thesis intends to accomplish four major objectives in relation to noise annoyance perception. Firstly, it aims to study the inter-relationships among sound characteristics, people's characteristics, and the environment by formulating a multivariate stochastic model to predict noise annoyance. Secondly, it aims to study the impact of a greenery view or a

sea view nearby on the moderation of noise annoyance perception at home. Thirdly, it is intended to evaluate the monetary benefits derived from reduced annoyance. All the above investigations are based on an underlying premise that road traffic was the major noise source. Accordingly, the final objective is to formulate an annoyance model to portray the response to a mixed road traffic noise and human noise situation. The mixed noises annoyance problem was addressed by conducting a series of laboratory experiments with individuals having similar socio-economic backgrounds, while a series of field surveys were carried out with residents of several housing estates in Hong Kong for addressing the remaining three objectives.

The findings derived from the multivariable stochastic models revealed that acoustical parameters, personal characteristics like age, education attainment, noise sensitivity and health conditions as well as the duration of time spent at homes all influence individuals' noise annoyance perception. The presence of several neighbourhood characteristics such as greenery and sea is able to lower the likelihood of inducing high noise annoyance. A sea view can moderate noise annoyance even though its effect is not as strong as a greenery view. Upon detailed examination, types and amount of greenery settings are shown to have different effects on moderating noise annoyance perception.

On the other hand, the willingness-to-pay (WTP) value for reduced annoyance is found to vary with the household income level and the annoyance rating reported by an individual for the existing dwelling. The WTP per dB reduction per household is found to be increased nonlinearly from HK$6.0 at 55 dB(A) to $8.5 at 75 dB(A) for the high income group, and from $4.8 at 55 dB(A) to $6.8 at 75 dB(A) for the low income group.

Under mixed noises situation, annoyance responses to ‘single dominant’ noise sources and ‘no dominant’ noise sources are found to be significantly different even under the same dB(A) level. Road traffic noise is found to be the dominant noise source in case the sound pressure level of the road traffic noise is higher than that of human noise by more than 6 dB(A).

The findings revealed from this thesis pose a significant contribution to the knowledge as both greenery and sea views are determined to be able to reduce noise annoyance. This has a profound impact on city planning and building designs as alternative and complimentary strategies are available for moderating noise annoyance at dwellings and promoting good well-being for modern city-dwellers. Of equal importance is that the protocol developed for estimating the monetary benefits arisen from reduced noise annoyance can be used to provide essential cost-benefit information for evaluating the financial viability of the proposed noise mitigation measures. Also, the formulated models for road traffic noise are also applicable for predicting annoyance responses from individuals living in residential dwellings which are exposed to both human and road traffic sources and the sound pressure level of road traffic noise is higher than that of human noise by more than 6 dB(A).

Keywords: Noise annoyance; Ordered logit model; Discrete Choice Model; Nature; Willingness-to-pay; Mixed-noise

PUBLICATIONS ARISING FROM THE THESIS

Journal papers:

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NOMENCLATURE

Symbols	Description
A_T	Total noise annoyance perceived
β_i	Coefficient estimate for parameter X_i
DR	Discount rate per year
ε_i	Error term in an econometric model
F	Fluctuation strength
GDP_{HK}	Gross Domestic Product value for Hong Kong
GDP_Z	Gross Domestic Product value in a particular country
L_T	Resultant noise levels from a combination of noise sources
M_i	A set of personally related characteristics
N_i	A set of neighborhood characteristics
ρ^2	McFadden's model fit parameter
S	Sharpness
μ_y	Threshold value for annoyance rating y
U_i	Overall utility of choice i in a discrete choice model
V_i	Deterministic component in a utility function
$WTP_{adjusted}$	Willingness-to-pay value after applying

	benefit-transfer
$WTP_{original}$	Willingness-to-pay value obtained in the country for which the research is conducted
X_i	Parameters in ordered logit function
Y^*_i	Annoyance rating assigned by individuals at sound pressure level i
Y_{g1i}	Dummy variable for classifying different types of setting and different amount of greenery
Y_{g2i}	Dummy variable for classifying different types of setting and different amount of greenery
Y_{g3i}	Dummy variable for classifying different types of setting and different amount of greenery
Y_{g4i}	Dummy variable for classifying different types of setting and different amount of greenery
Y_{g5i}	Dummy variable for classifying different types of setting and different amount of greenery
Y_{g6i}	Dummy variable for classifying different types of setting and different amount of greenery
Z_i	Ordered logit function at sound pressure level i
$E[\frac{WTP}{dB}]\|_x$	Average willingness-to-pay value at x dB(A)
$\frac{WTP}{annoyance}\Big\|_{gpi}$	Willingness-to-pay values for Group i

$\frac{annoyance}{dB}\Big\vert_{gpi}$	Annoyance-dB relationship for Group i
$\Pr(gpi)\vert_x$	Probability that a respondent would assign a particular annoyance rating at x dB(A)
$E[\frac{WTP}{annoyance}\Big\vert_{gpi\_with\_greenery}]$	Average willingness-to-pay value for respondents who are exposed to a greenery view at his home and have assigned a particular annoyance rating
$E[\frac{WTP}{annoyance}\Big\vert_{gpi\_without\_greenery}]$	Average willingness-to-pay value for respondents who are not exposed to any greenery view at his home and assigned a particular annoyance rating

CHAPTER 1

INTRODUCTION

1.1 The worldwide problem - environmental noise

Noise problems have received increasing concern in community nowadays. Considerable attention in the past and even now has been put on occupational noise (Concha-Barrientos et al., 2004). Recently, there is a growing interest on revealing the impact of environmental noise on human. Environmental noise, also known as community noise, is defined as noise emitted from all sources like roads, rails and air traffic, industries, construction and public work, and neighbourhoods but exclude industrial workplaces (Berglund et al., 1999).

Nowadays, ample evidence suggests that environmental noise has overwhelming effects on people worldwide. For example, 40% of the inhabitants in the European Union were exposed to equivalent noise levels exceeding 55 dB(A) during daytime and more than 30% exposed to the same noise levels during night time (The National Board of Health and Welfare, 2001). Interestingly, noise problem is the only environmental issue for which the number of complaints has increased in Europe since 1992 (European report, 1996). In the US, it was estimated that noise levels had raised by more than 11% over the last decade since 1991 and that noise levels would continue to rise at least as rapidly as the growth of general population (Suter, 1991).

Transportation is one of the major sources of environmental noise. It is believed that urban noise increased with road traffic flow, with bus and heavy truck being the main contributors (Seto et al., 2007). It was estimated that 22% of the population of the

European Union were exposed to transportation noise level exceeding 65 dB during the day, for which many European countries considered to be unacceptable (Miedema & Oudshoorn, 2001). According to the report issued by the Organization for Economic Co-operation and Development (1990), "Transport is by far the major source of noise, ahead of building or industry, with road traffic being the chief offender." In Hong Kong, noise pollution was ranked the third among the five studied social concerns, which include air pollution, security, traffic jam and cleanliness. More than a half of the respondents participated in a survey considered road traffic noise to be the most annoying source (Wong et al., 2002). All this evidence tends to suggest that environmental noise is a serious problem worldwide.

Environmental noise may cause many impacts, which include sleep disturbance, communication disturbance, myocardial infarction, ischemic heart disease, hypertension, hearing impairment, etc. Among them, noise annoyance is the most widely studied and concerned impact as just a daily noise exposure of 55 dB(A) was shown to be able to cause serious annoyance responses (Berglund et al., 1999). Nowadays, substantial efforts and resources have been spent on monitoring and mitigating the noise impacts within compact city areas by focusing mainly on reducing sound pressure level (Schultz, 1978; Sato et al., 1999; Klæboe et al., 2000; Korfali & Massoud, 2003). Unfortunately, ample evidence suggests that the correlation between sound pressure level and number of complaints is not as strong as anticipated (Job, 1988; Paunović et al., 2009), and the influence of non-acoustic factors in relation to source, receiver and context on community's noise reactions has been determined to be as significant as pure acoustic factors (Miedema & Vos, 1999; Jakovljevic et al., 2009). None of the models explored the effect of neighbourhood environmental characteristics, like greenery and sea, on the perception of noise annoyance. Above all, few models developed so far can predict an individual's annoyance response based on a multitude of acoustic and non-acoustic factors. Besides, there is no protocol available for estimating the monetary benefit gains arising from reduced annoyance or the value of nature for reducing annoyance in a probabilistic manner. Also, it is of paramount interest to explore whether the annoyance prediction model can be applied to a mixed noise situation, e.g. in the presence of both human and road noise, which is quite common in Hong Kong. Accordingly, the major objectives of this thesis are summarised as follows.

1.2 Objectives

This thesis aims to:

i. investigate the effects of individuals' perception of greenery and sea views on their noise annoyance responses at homes;

ii. formulate a model to predict the likelihood of giving different degrees of noise annoyance responses based on a multitude of acoustic, socioeconomic and neighbourhood environmental factors;

iii. evaluate the monetary benefit gains arisen from reduced annoyance and the value of nature for reducing annoyance by deriving the willingness-to-pay estimates. Models have been formulated for expressing willingness-to-pay as a function of a multitude of acoustic, personal and neighbourhood characteristics;

iv. determine whether the annoyance responses to a mix of road traffic noise and human noise vary with the noise composition. Experiments have been designed to predict whether a single dominant human noise or a single dominant road traffic noise contribute to the same degree of noise annoyance as a combined human noise and road traffic noise.

1.3 Significance of the findings

The findings arisen from this study can inform city planners and building designers that alternative and complimentary planning and design strategies are available for moderating noise annoyance at dwellings and promoting good well-being for modern city dwellers. The findings on whether greenery or sea in proximity to residential estates can help alleviate the problem of noise annoyance should lead to the development of an alternative and complimentary annoyance moderation strategy for urban planning. Besides, the findings derived from the model can help identify individual sub-population groups who are more susceptible to noise annoyance problem such that more attention can be put on these subgroups. Of equal importance is that the findings can also provide solid evidence for policymakers to formulate a set of neighbourhood planning and building design guidelines for promoting better quality of life.

In addition, the willingness-to-pay values can be used to estimate the benefit gains of reduced noise annoyance and to evaluate the cost-effectiveness and value benefits of the proposed strategies and measures. Different noise mitigation strategies can then be compared for identifying the most financial viable strategy.

1.4 Outline of this thesis

The general layout of this thesis is outlined as follows. Chapter 2 provides a comprehensive literature review on impacts of environmental noise. The potential impacts arisen from environmental noise exposure are summarized. With noise annoyance being identified as the major impact, the appropriate noise metrics and survey protocol for evaluating noise annoyance are discussed. Recent research findings are included in the latter part of this chapter and factors that may affect the perception of noise annoyance are discussed.

The factors that may affect individuals' perception of noise annoyance are identified in Chapter 3. In addition to the commonly studied acoustical and socioeconomic factors, the neighbourhood environmental characteristics like sea views and greenery views are intensively studied. Multivariate models have been formulated to predict the likelihood of an individual to give a lower annoyance response and the probability is expressed in terms of a list of personal and neighbourhood characteristics, in particular perception of greenery or sea from home. Broadly speaking, Chapter 3 can be systematically divided into two parts. The first part focuses on the extent of noise annoyance responses that can be reduced by perception of different types of greenery settings and different amount of greenery. The second part focuses on revealing whether the moderation effects of sea view and greenery view vary with some receptor's personal characteristics.

Chapter 4 attempts to reveal how a resident makes a trade-off decision between noise annoyance and other apartment-related attributes like monthly rent and management fee of apartment, and the monetary value for reducing noise annoyance is derived. It is also intended to examine whether the monetary value estimates vary with personal characteristics like monthly income and background noise level. This is very important for urban development.

Chapter 5 evaluates whether the models developed in previous chapters can also be applied to the presence of both human and road traffic noise are in residential estates. A series of controlled laboratory experiments were set up to investigate whether the annoyance responses to a mix of road traffic noise and human noise vary with the noise composition. Chapter 6 is the final chapter which presents the conclusions and recommendations of this study.

CHAPTER 2

A LITERATURE REVIEW ON ENVIRONMENTAL NOISE

2.1 Adverse effects from environmental noise

The literature review on environmental noise in this chapter starts off with an overview of the major impacts from environmental noise. Generally, environmental noise impacts can be broadly classified into short-term and long-term effects. Short-term effects include sleep disturbance (arousal route), communication disturbance (sound masking route) and concentration disturbance (attention route). On the other hand, long-term effects include annoyance, cognitive impairment, and cardiovascular diseases like myocardial infarction and ischemic heart disease (Miedema, 2007). Others also regarded hypertension as an adverse health impact caused by road traffic noise (Öhrström et al., 2007). Arguably, long-term noise effects are often related to health impacts rather than emotional impacts, and they were considered to be the consequences of an accumulation of short-term emotional stress (Rylander, 2004).

2.1.1 Sleep disturbance

Environmental noise has already been shown to be an agent for causing sleep disturbance (Stansfeld et al., 2000). A study in Norway showed that 6.1% of urban residents exposed to railway noise blamed environmental noise as the major agent for causing them difficulties in falling asleep or awakening during the night (Aasvang et al., 2008). Environmental noise may affect sleep in various ways. It can lead to degradation in sleep quality, disturbance of functioning, performance or mood in the following day.

Noise of sufficient intensity may affect sleep pattern, and cause an increase in the number of people reporting difficulties in falling asleep. Noise exposure during sleep may increase blood pressure, heart rate and finger pulse amplitude as well as body movements (Hollander et al., 2004).

Earlier evidence has indicated that noise may cause sleep disturbance. Awakenings during sleep by noise are regarded as the major consequence of sleep disturbance. The number of awakenings was found to be proportional to the noise exposure experienced by residents in night and across nights (Öhrström et al., 1988). There may be some habituation effects to sleep disturbance by noise, however, complete habituation does not occur, in particular for heart rate (Vallet et al., 1983).

Exposure to noise also induces secondary effects, which are measured the day following a night-time exposure, while an individual is awaken (Berglund et al., 1999). Secondary effects include lower perceived sleep quality, increased fatigue, depressed mood or well-being, and degraded performance.

Sleep disturbance would occur if more than 50 noise events occurred per night with a maximum level of 50 dB(A) indoors (Stansfeld & Matheson, 2003). And a reduction of noise level by 6-14 dB(A) was found to be beneficial for relieving the problem of sleep disturbance (London Health Commission, 2003).

2.1.2 Communication disturbance

Results from many laboratory tests suggest that noise exposure impairs mental performance (Hollander et al., 2004). Performance is impaired by irrelevant conversation nearby as noise from conversation may contribute to arousal, alter task strategy, and distract attention to the performing task, and the effects depend on the intensity and meaning of the speech. Noise exposure may also slow rehearsal in memory, influence processes of selectivity in memory, and choice of strategies for carrying out tasks (Smith & Broadbent, 1992). There is also evidence indicating that noise may reduce helping behaviour, increase aggression, and reduce the processing of social cues seen as irrelevant to task performance (Jones et al., 1983). The susceptibility of complex mental tasks to disruption by 'irrelevant speech' also suggests that reading, with its reliance on memory, may also be impaired. Many activities involving speech can be severely interfered by environmental noise.

Among all, tasks that involve central processing and language comprehension, like reading, attention, problem solving and memory appear to be mostly influenced by noise (Stansfeld & Matheson, 2003). Prolonged exposure to noise is found to be associated with deficits in sustained attention, visual attention and concentration, with poorer auditory discrimination and speech perception, memory impairment, and poor reading ability and school performance.

2.1.3 Cardiovascular syndromes

Common cardiovascular syndromes caused by excessive environmental noise include myocardial infarction, ischemic heart disease and hypertension. In a meta-analysis of 43 studies in relation to noise exposure and heart diseases, exposure to road traffic noise was associated with a higher risk for myocardial infarction *(*van Kempen et al., 2002). People exposed to outdoor traffic noise levels above 70 dB(A) during the day were 30% more likely to suffer from myocardial infarction than those exposed to noise levels below 60 dB(A). The chance was found to increase to 80% in case they had lived at their present address for more than 10 years (Babisch et al., 2005). Other factors like people with diabetes, family history of myocardial infarction as well as smoking habit may also be the cause of myocardial infarction. Nevertheless, a strong correlation has not yet established and a concrete conclusion could not be drawn.

Although noise annoyance was reckoned to be associated with ischemic heart disease incidence in Babisch's study (Babisch et al., 2003), the findings revealed from a recent meta-analysis suggested that the relationship between noise exposure and ischemic heart disease was still inconclusive. The inconclusive results are probably due to the limitations inherent in exposure characterization, adjustment for important confounders, and the occurrence of publication bias (van Kempen et al., 2002).

Further, hypertension is also a common cardiovascular syndrome associated with elevated noise levels. A positive association was found between noise level and the occurrence of hypertension, and the association was stronger at higher noise levels (Öhrström et al., 2007). Elevated blood pressure levels were observed for school-aged children living or going to school near a major transportation noise source with noise level being ranged between 95 dB(A) and 125 dB(A) (Evans & Lepore, 1993). It was almost twice as likely that people living in noisy neighbourhoods for more than 10 years had hypertension as those who did not live in noisy neighbourhoods (Barregard et al., 2009). Gender and length of residence were also associated with the incidence of hypertension and use of hypertension medication (Bluhm et al., 2007). Nevertheless, the association between long-term environmental noise exposure and hypertension was found to be weak (Berglund & Lindvall, 1995).

Although a small effect on cardiovascular health risk under noise exposure, as mentioned in the above studies, is deemed highly plausible, the statistical evidence for a causal relation between noise exposure and cardiovascular health risk is considered to be on the verge of conclusive (Hollander et al., 2004). Several methodological shortcomings may cause this problem. First, the exposure assessment is inadequate as many of the studies were of the cross sectional type. Second, a majority of studies had limited possibilities of controlling confounding variables like employment status, neighbourhood effect, and selection bias which are extremely important with respect to the occurrence of cardiovascular disease.

2.1.4 Hearing impairment

Hearing impairment is a widely recognized noise impact. A hearing handicap is defined as the disadvantage imposed by hearing impairment sufficiently severe to affect one's personal efficiency in the activities of daily living (ISO 1999). The hearing handicap is usually evaluated in terms of the capability of understanding a conventional speech in low levels of background noise.

Affecting the understanding of speech is usually regarded as the major consequence of hearing impairment. Hearing loss is considered as a severe social handicap owing to the fact that speech is the most efficient means of social communication. Approximately 10 million people in the US had permanent or irreversible hearing loss from noise or trauma (Healthy People, 2010).

In a case control study, noise-exposed persons were found to have much higher degree of shearing losses than their relatively unexposed age cohorts (Rosen & Olin, 1965). Noise-induced hearing loss can be the result of continuing exposure to high levels of sound in the workplace or in recreational settings.

The problem of hearing impairment is of particular concern if there is a prolonged exposure to loud music during leisure activities like attending concerts and listening to music through headphones (Passchier-Vermeer & Passchier, 2000). This is especially the case when the peak sound pressure level exceeds 120 dB(A). A cumulative exposure to relatively moderate levels of 70 dB(A) already leads to an irreversible loss of hearing (Rosenhall et al., 1990). Despite so, the risks for hearing impairment at typical environmental levels of exposure are rather low.

2.1.5 Cognitive development of children

In order to examine the chronic effect of aircraft noise on the reading comprehension ability of children, experiments were carried out at two schools (Evans & Maxwell, 1997). One of which was a quiet school and another was a relative noisy school where planes from a nearby airport flew over every 6 minutes with the resulting classroom decibel levels being 90 dB(A). The experimental results suggested that children from the noisy school performed poorer in reading than the counterpart.

The observation can possibly be explained by the fact that long term exposure to road traffic or aircraft noise could impair cognitive development in children, like reading comprehension, speech intelligibility, recognition memory, motivation, attention, problem solving, and performance on standardized tests (Stansfeld et al., 2005), even though their sustained attention, self-reported health, and overall mental health were not impaired.

Also, some evidence suggested that children exposed to environmental noise in a long term would have significant delays in reading (Evans, 2006). Noise exposure also slowed down the rehearsal in memory, influenced processes of selectivity in memory and choice of strategies for carrying out tasks (Stansfeld & Matheson, 2003). In particular, exposure to uncontrollable noise made children more vulnerable and children generally performed discrimination tasks better in quiet environment than in noisy environment (Evans & Maxwell, 1997).

2.1.6 Annoyance

Annoyance is the most-studied response to noise exposure, probably due to its subjective nature such that it is relatively easy to be assessed. It is less well-defined as compared with other noise impacts, possibly because the phenomenon of noise annoyance is too complex for us to give an exact definition to noise annoyance. An earlier definition of annoyance is given as “a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them” (Koelega, 1987). However, other negative emotions like anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion were also conceived to be part of noise annoyance responses (Job, 1993).

Indeed, problems of noise annoyance have been frequently reported worldwide. Thirteen-percent of the sampled individuals exposed to road traffic noise above 50 dB(A) for 24 hr reported the annoyance problem (Bluhm et al., 2004). In particular, the risk of annoyance caused by noise increased by forty-percent if an individual was living along an arterial urban street (Seto et al., 2007).

The degree of annoyance provoked by noise exposure depends on a number of factors including sound level, spectral characteristics and variations with time of the day or season. However, noise level could only explain 25-30% of the observed variance in the annoyance response reported (Hollander et al., 2004). On the other hand, it is suggested that the degree of annoyance was also influenced by non-acoustical factors like age, psychological status, individual noise sensitivity and fear with respect to the source (Guski, 1999; Job, 1999, Stallen, 1999). Noise annoyance is always assessed through surveys. Road traffic noise, railway noise and aircraft noise are the most common environmental noises that have been evaluated so far. Annoyance-response relations have been established for these noises. They are often given as a percentage of the people who are highly annoyed or as a mean annoyance level under a particular noise level.

2.2 Noise surveys for eliciting annoyance responses

Noise surveys are often utilized to elicit noise annoyance responses. Usually respondents are interviewed to elicit their responses to a specified noise source at their residences. The collected responses will be analyzed with a main focus on understanding the annoyance responses from respondents to the acoustical noise environment, and how these responses are affected by a range of personal and social characteristics.

Although eliciting noise annoyance responses through noise surveys is a universal practice until now, it is often recognized that inconsistencies in the reporting of research results hinder the accumulation of knowledge from these noise surveys.

Studies lacking the basic information about the survey details sharply limit the conclusions that can be drawn about dose-response relationships and the effects of other variables on noise annoyance. Only a small proportion of studies have contributed to the broader goal of developing generalizable knowledge about the annoyance responses to environmental noise. Efforts have been made to develop professional standards for guidelines for the development of noise survey data collection protocol. Professional standards for the reporting of social survey data were established by public opinion organizations (American Association for Public Opinion Research, 1996). Professional standards for acoustical report statements are also available in ISO Standards. It is recognized that survey data reporting standards are as important as survey data collecting standards, and guidelines for reporting core information from community noise response surveys were also established (Fields et al., 1997). In essence, a noise survey should embrace the collection of basic information about the survey details like survey date, survey location, site selection, sample size, survey methods in the reporting.

2.2.1 Noise annoyance scales

Revealing noise annoyance response is always a crucial focus in a noise survey. Noise annoyance responses are often elicited using verbal or numerical noise annoyance scales. Verbal scales normally do not have more than five points as too long a scale makes the annoyance rating task too cumbersome, while scales of one or two point are not utilized as the range of alternatives is not sufficient to reveal the difference in ratings (Fields et al., 2001). The verbal scale is needed for the clearest presentation of the degree of annoyance to the respondents (ISO, 2003). It is expected that choosing a word from the verbal scale is easy to be performed by respondents of any degree of sophistication in any culture. In a typical verbal scale the annoyance responses were elicited from respondents by asking them whether the noise they exposed to was ‘highly annoying’, ‘somewhat annoying’ or ‘not annoying’ (Norwegian Pollution Control Agency, 2000). On the other hand, numerical scales have been frequently used as the scale points are equally spaced, for which the assumptions for regression techniques can be met (Fields et al., 2001). The use of numerical scale also reduces the possibility of distortion by idiosyncratic interpretations of the verbal labels for scale points. A 0-10 mono-polar numeric scale (‘0’-10 graded; ‘0’ stands for ‘Not at all’ and ‘10’ stands for ‘Extremely’) has been recommended to be used for eliciting annoyance responses in surveys (ISO, 2003).

Since both verbal and numerical scales have their own merits and drawbacks, it is not uncommon to use both scales in the same noise survey to reveal the noise annoyance responses so that more reliable annoyance responses can be obtained.

2.2.2 Noise metrics

In addition to noise annoyance responses, noise survey should always specify the noise metric utilized in the survey. The most common noise metrics employed in a noise survey include L_{Aeq} and L_{MAX}. L_{Aeq} refers to the A-weighted equivalent sound energy level over a specified period of time, for example, 24 hours, as adopted in some previous studies (Sato et al., 1999). Another study, which analyzed the annoyance caused by a high-speed train, adopted a L_{Aeq} of 45 second instead (de Coensel et al., 2007). The A-weighting is commonly used in noise surveys and is intended to correlate the frequency response of human hearing system. L_{MAX} refers to the maximum sound energy level within the time frame under consideration (Berglund, 1999). Different noise metrics have different applications. L_{Aeq} is considered to be more appropriate when the sound is continuing, like in the case of road traffic noise. L_{MAX} is often used when noise disturbance is caused by small numbers of discrete events. Distinct events from noise sources like aircraft noise and railway noise are often measured by L_{MAX}. L_{MAX} is also more preferred in describing irregular noise situations, especially when the background noise level is low.

Other noise metrics like the day-night average sound level (*DNL*) and the day-evening-night average sound level (*DENL*) have also been used to represent the average noise level over a twenty-four hour period. The *DNL* differs from L_{Aeq} in that a 10 dB penalty is applied to the noise level measured at night. *DENL* further penalizes the noise level in evening by 5 dB. *DNL* and *DENL* have been mainly applied in evaluating the aircraft noise annoyance problem.

Further, some psycho-acoustical parameters like loudness, sharpness, fluctuation strength and roughness have also been used to model annoyance responses. Loudness differs from A-weighting in that it also measures the magnitude of noise volume and reflects the spectral masking characteristics of the human ear. Loudness is a value used to represent how human perceive a particular sound volume. It is often measured in *sones*, for which a sone refers to a sound of 1 kHz tone at a level of 40 dB.

Sharpness is also used to characterize steady-state noise. It differentiates two sounds of equal loudness by focusing on the proportion of loudness within high critical frequency bands. The sound with greater sharpness has louder frequency components within the high frequency bands, which are more sensitive to human ear. Sharpness is measured in *acum*, which is referenced to a narrowband noise centred at 1 kHz with a level of 60 dB.

Fluctuation strength is used to characterize dynamic noise. It takes into account the temporary variation in the loudness spectrum due to frequency modulation between 0.25 Hz and 20 Hz. Fluctuation strength is measured in *vacil*, which is referenced to a 1 kHz tone at 60 dB that is frequency-modulated by a 4 Hz sine wave with a modulation factor of one. Roughness is also used to characterize dynamic noise, but focuses on the temporary variation in the loudness spectrum due to frequency modulation between 20 Hz and 300 Hz. Roughness is measured in *asper*, which is referenced to a 1 kHz tone at 60 dB that is frequency-modulated by a 70 Hz sine wave with a modulation factor of one.

2.3 Research studies following the annoyance approach

Earliest research studies adopted the annoyance approach to study the relationship between noise source characteristics and the associated annoyance responses. A regression model is often formulated for revealing the annoyance-response relationship under the annoyance approach. The earliest noise survey conducted to elicit the annoyance responses from respondents can be dated back to 1978 (Schultz, 1978). In this study, acoustical sound energy level was found to associate with annoyance responses and a relationship between *DNL* and percentage of respondents highly annoyed was derived. However, it is later revealed that acoustical factors could merely account for 20% of the variance of annoyance response (Job, 1988). Recently, there is a growing body of evidence suggesting that non-acoustic factors like personal characteristics are as important as sound pressure levels in influencing noise annoyance responses. However, up to now, there is little consensus on how personal characteristics affect noise annoyance responses. Miedema and Vos (1999) found that more educated individuals tended to report higher annoyance, but Klæboe et al. (2004) and Fields (1993) did not find any relationship between education status and noise annoyance perception. Pathak et al. (2008) revealed that unmarried people was more significantly affected by noise annoyance but Klæboe et al. (2004) and Fields (1993) did not find any relationship between them. Klæboe et al. (2004) found that the youngest age group suffered more from noise annoyance, but Miedema and Vos (1999) found that not only the younger age group but also the older age group suffered more from noise annoyance. All in all, noise sensitivity is apparent to be the only personal characteristics that have been confirmed to exert influences on the perception of noise annoyance (Fields, 1993; Miedema and Vos, 1999).

In evaluating the correlation between noise annoyance and socioeconomic factors, different types of models have been applied for the analysis. Pathak et al. (2008) applied a chi-square model to analyze the relationship between annoyance perception and marital status, and a *p*-value of less than 0.05 was found from the chi-square test. This suggested that the null hypothesis (no relationship between annoyance perception and marital status exists) can be rejected and the correlation did not occur by chance.

Miedma and Vos (1999) applied a multivariate linear regression to analyze the effects of various socioeconomic variables on the annoyance perception. They evaluated the relative contribution of the individual socioeconomic factor to the explained variance of noise annoyance. Besides noise sensitivity, the attitudinal factor 'fear' was also found to have great influence on the perception of noise annoyance. Klæboe et al. (2004) used an ordinal logit model to establish an 'empirical' relationship for annoyance-response. The effects from different age groups were also analyzed in their model. Individuals aged between 20 and 29 years old suffered the most from noise annoyance. A smaller yet noticeable effect was also observed for individuals aged between 30 and 39 years old.

Even though many acoustical and socioeconomic factors have been embraced in formulating annoyance-response functions, it is recognized that the size of variance explanation of the annoyance-response functions, as revealed by the magnitude of the model fit information like r-square, is still limited. Guski (1999) suggested that one-third of the annoyance variation could be explained by acoustical factors including sound level, peak levels, sound spectrum, etc; and another one-third could be explained by non-acoustical factors like socioeconomic factors as above. And the remaining one-third would be due to the presence of unknown factors which could also influence the perception of noise annoyance.

2.4 The need of a soundscape approach

Later, Schulte-Fortkamp & Nitsch (1999) suggested soundscape as a new approach towards the traditional theory of noise annoyance. The traditional annoyance approach attempts to investigate the acoustical environment at a micro level, which refers to the analysis of acoustical composition of noise events and psycho-acoustical parameters. The characteristics of the noise source and the people with a particular personal characteristic who are actually suffering from the problem of noise annoyance are the main focus at this micro level.

The soundscape approach differs from the traditional annoyance approach in that it also considers the macro level of the acoustical environment. The macro level refers to the descriptions of noise events that are happening in the comparable soundscapes like streets, urban areas and towns. As the visual scenes of the soundscapes and the matching of the visual scenes with the noise events are also taken into account in the soundscape approach, a more comprehensive explanation to the perception of noise annoyance can been accomplished with.

2.4.1 A review of soundscape approach in evaluating annoyance responses

The soundscape concept is introduced as a scope to evaluate noise annoyance responses observed in socio-acoustical noise surveys. The word “soundscape” was first introduced by Schafer (1969) to denote an auditory equivalent to (visual) landscape, defined as an environment created by sound. The concept of soundscape explicitly includes a subjective component, namely the way in which the environment is perceived and understood by an individual or by a community (Truax, 1978).

Soundscape suggests exploring noise in its complexity and its ambivalence, and hence soundscape research tends to investigate the conditions and purposes of its production, perception, evaluation, which account for a human-centred point of view (Schulte-Fortkamp & Dubois, 2006). The soundscape environment is considered as a mediator between humans, their activities and the environment. The soundscape approach aims to study the improvement of the relationship between the living environment and the soundscape (Wrightson, 2000). Soundscape assessment should be dedicated to evaluate not only acoustical but also other sensory, aesthetic, geographic, social, psychological and cultural modalities in the context of human activity across space, time, and society (Schulte-Fortkamp & Dubois, 2006). In a soundscape assessment, emphasis is placed on examining noise not just by its physical properties, but also by studying the social meanings attached to the sound, and also the relationship between the perceiver response and the environment.

2.4.2 Natural environment as a rural soundscape

Many recent soundscape researches tended to accentuate the positive aspects of rural soundscapes and highlight the negative aspects of urban soundscapes. This is logical because natural environments like rural soundscape can enhance individual's health and well being by providing physiological and emotional restoration (Herzog et al., 1997; van den Berg et al., 2003). Human basically respond positively to natural contents by engaging the mind and promoting a positive emotion of well-being, particularly when they are mentally fatigue (Tennessen & Cimprich, 1995). Natural environment can help relieve stress by reducing blood pressure and muscle pains, and by restoring from mental fatigue (Ulrich et al. 1991). The positive emotions aroused helps reduce unpleasant thoughts and feelings and hence foster physiological stress recovery.

The term tranquillity has also been utilized to refer to the rural soundscape environment. Relative tranquil rural areas are believed to be more likely to provide people with the space and conditions to relax and allow them to withdraw from stress. Several important elements characterize the nature of a relative tranquil area: a low density of people, a low level of artificial noise, and a relatively natural landscape appearance with little human influence on the territory (Ray, 2006). According to the Attention Restoration theory (Kaplan, 1995), tranquil area facilitates ‘effortless attention’ which is contrasted with urban area. The tranquil area enables an individual to recover from attentional fatigue and promotes a sense of psychological well-being. However, the value of tranquillity is mediated through individual perceptions and depends very much on individual experience.

2.4.3 Visual scenes in altering noise annoyance perception

The role of natural environment or tranquil area in altering the perception of soundscape has eventually led to the investigation of the interaction between audio and visual perception, and its effect on noise annoyance response. Aesthetically pleasing scenes have been shown to be able to influence an individual’s noise annoyance response by altering the perception of soundscape. Bad visual scenes would contaminate judgments of what being heard (Viollon et al., 2002). Visibility of noise sources directly from their homes was generally reported to be suffered more from noise annoyance (Bangjun et al., 2003). A positively evaluated landscape (Maffiolo et al., 1999), a simple presence of, or a better accessibility to parks and nearby green spaces could reduce the long-term noise annoyances of resident dwellers (Gidlöf-

Gunnarsson & Öhrström, 2007), or lower dissatisfaction with traffic noise (Kastka & Noack, 1987). However, most of the past efforts tended to only suggest that an association existed between the existence of natural greenery and noise annoyance reduction. It is only until recently that the amount of greenery was shown to exert different moderation effects on noise annoyance (Gidlöf-Gunnarsson & Öhrström, 2007).

2.4.4 Recent soundscape researches

Nowadays, soundscape researches have been carried out in different dimensions. Given the complexity of soundscape evaluation, it is often not feasible to take all potential soundscape modifiers into account in one single study. Jang and Kook (2005) intended to identify the best introduced sound in several visual landscapes including park, garden, bus terminal and street. The studied sounds included existing sound at each visual landscape, streaming water sound, environmental music, gayageum music, guitar music, music box sound, sea gull sound, wave and boat whistle sound, cuckoo sound, fulling cloth sound, Korean fusion music, piano music, wind bell sound, locust sound, water sound at valley, and sound from temple bell. And their results showed that the best introduced sound varied from location to location. Temple bell was rated to be the best introduced sound along the park pathway, but wave and boat whistle sound was rated the best at the hill with ocean view in the park. Artificial music like guitar sound could be helpful in the street but not in the bus terminal which was more crowded and noisy. On the other hand, almost all of the sounds were found to worsen the sound environment inside the garden. Matching of sounds with a visual landscape is a very important element in the soundscape environment.

Ge and Hokao (2004) aimed to study the effect of various sounds on the whole soundscape inside the Saga Forest Park in Japan. The soundscape components fell into four categories: natural sound, silence, social sound and artificial sound. The natural sounds included tree rustling sound, water flowing sound and chirping sounds from birds and insects. The social sounds were mainly from children playing and conversation. The artificial sounds were mainly from music and announcement. The results suggested that natural sound and silence accounted for about seventy-percent of the soundscape components and they were the most important soundscape component inside the Park. Following this observation it was suggested that more species of plants and waterfronts should be included in order to induce more natural sound sources and therefore enhance the soundscape of the Park. Further, different soundscape zones have been proposed to fit the different purposes of the Park. For example, it was suggested that the sports/games playing zone and resting zone in the Park should have a different soundscape component.

Berglund & Nilsson (2006) utilized structured listening walks to evaluate the soundscape quality of residential areas. Soundscape quality of the exposed side and shielded side of buildings was carefully examined under three scenarios namely outdoor, indoor with open window and indoor with closed window. The soundscape quality of the shielded side of a building was assessed to be less adverse than the exposed side provided that the noise level was not high. It was also revealed that the soundscape quality could not be solely determined from noise level. Even though the sound pressure level from indoor environment could be much less than the outdoor environment, the soundscape quality was not rated significantly better. This suggested that the building structure inside the soundscape could also affect the soundscape quality in addition to the nature of sounds and the visual scenes.

Yang & Kang (2005) intended to examine the human sound preference in urban squares. The common categories of sounds found in the urban square included traffic, machinery, surrounding speech, birds and wind. Same as previous researches, natural sounds were found to be more favourable than urban sounds. In addition, age of respondents was shown to exert a significant impact on how people perceived the sounds. Older people tended to be more favourable to natural sounds. This showed that the sound preference could also be influenced by personal backgrounds in addition to the nature of sound.

Lavandier & Defréville (2006) intended to evaluate urban soundscapes by the contribution of sound source characteristics. Urban soundscapes under examination included classical street, market and park in Paris. The common sound categories identified in their study included car, moped, motorcycle, bus, adult voices, child voices and birds. In addition to the energetic characteristics of sound sources, they also included the time characteristics of sound sources in their analysis. Their analysis suggested that the incorporation of the information about sound source characteristics to the perceived loudness could help explain the variances observed in the subjective evaluation of urban soundscapes, and sole recognition of decibel level was insufficient in the evaluation of soundscapes.

Semidor (2006) proposed the soundwalk method for soundscape evaluation. Sound recordings were performed with a binaural system while invited participants were walking along a route with different urban forms. Based upon such an approach it was expected that information of the sound environment recorded by the equipment could be associated with visual urban scene as well as urban activities as experienced by the participants along the walk.

Lam et al. (2010) studied the correlations between human preference of soundscape and the perceptual terms including quietness, joyfulness, activeness, stableness and naturalness. They found that many perceptual factors had considerable correlation with soundscape preference. In their study the effects of different types of sounds including stream, bird, sea waves, wind, waterfall, insect, human, road traffic and aircraft on soundscape preference were also analyzed. Their results suggested that acoustical metrics accounted for the human preference of sound to a limited extent. In general, lower preference scores were observed for unwanted sounds like human noise and transportation noise. This once again emphasized the importance of the nature of sound on soundscape composition.

CHAPTER 3

EFFECT OF NATURE PERCEPTION ON NOISE ANNOYANCE

3.1 Relationship between nature and noise annoyance

The capability of natural environment in moderating noise annoyance responses may be explained by resorting to a number of Psychology literatures that visual conditions can modify the auditory perception of subjects (Viollon & Lavandier, 1997). Perception of nature attracts and holds a person's attention effortlessly and to some involuntarily. Being in nature gives a person a sense of being away from daily routines that impose demands on directed attention, thus reducing stress from the acoustical environment (Kaplan, 1995). Stress from urban life in general, such as noise from traffic, may motivate people to look for natural environment (van den Berg et al., 2007), as contact with natural environment promotes a relatively effective way for reducing stress compared to ordinary urban environment (Health Council of the Netherlands, 2004). Despite so, little field evidence successfully proved whether perception of nature can reduce noise annoyance at home.

3.1.1 Greenery

Greenery has become an indispensable element for an urban city due to numerous benefits being provided for mankind. In particular, greenery maintains a balance of eco-system by ameliorating climate (Shashua-Bar & Hoffman, 2000; Wong & Yu, 2005), and filtering air, water and soil of many pollutants and providing a habitat for fauna and flora. Inner city greenery is especially important for improving air quality via uptake of pollutant gases like ozone and via the high particulate dust-binding capacity of leaves (McPherson et al., 1998). Large green area could bring down the air pollutant levels of nearby urban areas (Kuttler & Strassburger, 1999).

Findings from recent research programs within the EU on urban green spaces confer their role as improving people’s life quality (Priestley et al., 2004). An epidemiological study performed in the Netherlands showed that residents of neighborhoods with abundant green space tended to enjoy better general health, and in particular for elderly, housewives, and people with low socioeconomic status. Experienced stress was reported to be less upon a more frequent visit to green spaces (Grahn & Stigsdotter, 2003). A neighborhood with comparatively plentiful walkable green space was essential in lowering the risk of mortality (Takano et al., 2002).

Some past studies had also suggested that greenery might be able to alleviate the problem of noise annoyance. For example, the presence of parks and green spaces could lower dissatisfaction for traffic noise (Kastka & Noack, 1987). Better accessibility to nearby green spaces could moderate long-term noise annoyances and thus could improve individuals’ well-being (Gidlöf-Gunnarsson & Öhrström, 2007).

3.1.2 Water sources

While numerous efforts have been put onto analysing the benefits brought about by green spaces, aquatic environments have also been under close examination recently as people tend to appreciate the aesthetic value of water (Miller, 1998). Water is one of the most important and attractive visual elements of landscape (Burmil et al., 1999). Water features generally received favorable ratings because of their association with scenic beauty (Blankson & Green, 1991), and the aesthetic value of water is supported by an observation that people in general differentiate landscapes with and without water and they tend to favor landscapes with water (Wherrett, 2000).

However, there is mixed evidence about the positive impacts of water sources on individuals' well-being or restorative power. On one hand, aquatic environments were reckoned to be able to enhance individuals' well-being by providing cognitive restoration and relaxation (Laumann et al., 2001). Natural and built scenes containing water were associated more with higher preferences, greater positive effect, and higher perceived restorative power than those without water (White et al, 2010). Arguably, certain visual properties of aquatic environments contribute to the attractive and potentially restorative characteristics. For example, water reflects light in interesting ways and certain lines and patterns of light are considered to be more restorative than others (Fernandez & Wilkins, 2008). On the other hand, water sources have not always been shown to able to provide restoration and relaxation effect. Scene with water was not found to alleviate fear, anger and stress more compared with scene without water (Ulrich et al., 1991). The presence of a creek was not found to lower stress, anger, depression and tension, as compared with the absence of a creek (Van den Berg et al., 2003).

3.1.3 A conceptual model among nature and noise annoyance

In view of inconclusive evidence on the restorative effects provided by water sources, it is hypothesized that perception of a sea view at home can moderate noise annoyance at home and the length of stay at home will affect its moderation effect. Also, it is hypothesized that a greenery view can moderate noise annoyance at home as some previous studies suggested a greenery view could alleviate the problem of noise annoyance (Kastka & Noack, 1987; Gidlöf-Gunnarsson & Öhrström, 2007),. Above all, noise annoyance is influenced by sound properties and personal characteristics. A conceptual model has been formulated to depict the above picture and is shown in Figure 3.1.

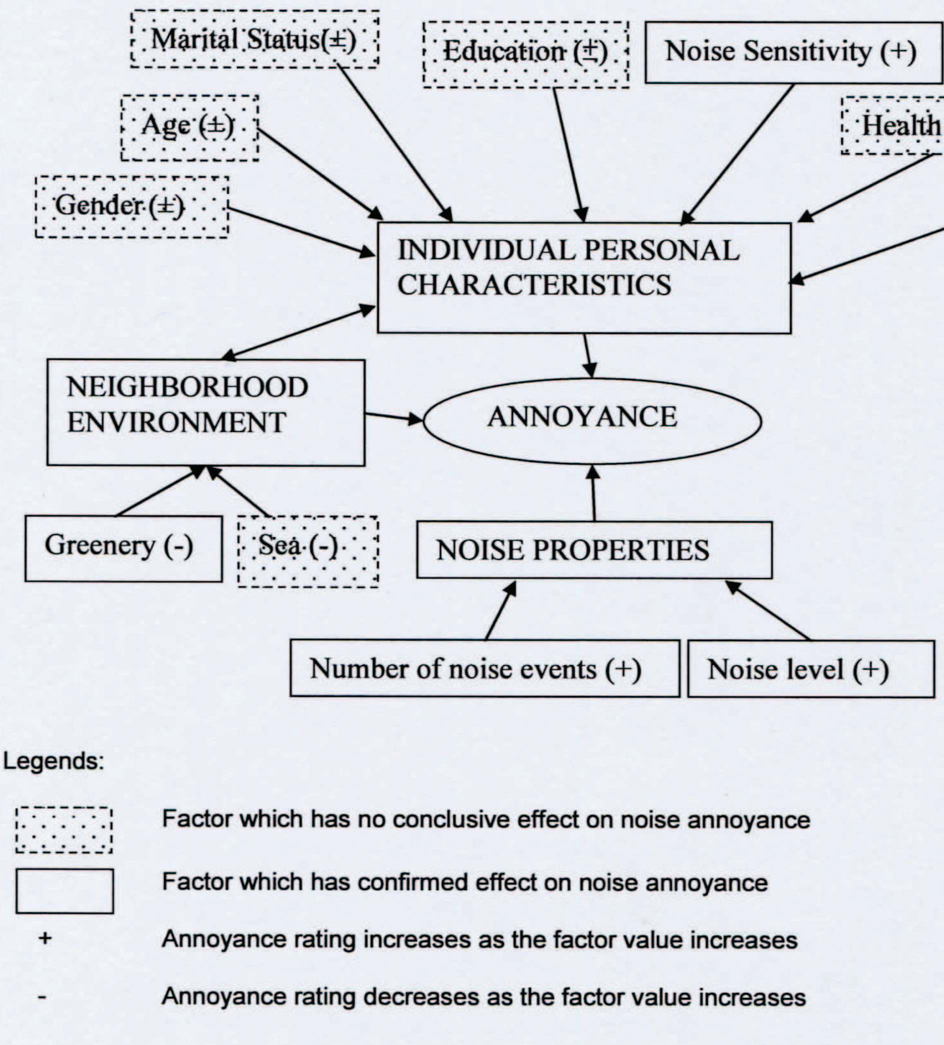

Figure 3.1 A conceptual model showing the relationship between noise annoyance and its factors

Based upon the interrelationships shown in the conceptual model, multivariate stochastic models were constructed by embracing annoyance rating as the dependent variable and other confirmed and potential factors as the independent variables for both Study I and Study II in this chapter.

3.1.4 Aims of this chapter

The ultimate aim of this chapter is to investigate whether perception of nature can moderate an individuals' noise perception at homes. Of particular interest is whether greenery and sea can moderate noise annoyance perception. Accordingly, three objectives are defined for this chapter. Firstly, it aims to reveal whether perception of greenery at homes can moderate noise annoyance perception, and whether different types of settings or amount of greenery could lower noise annoyance to different degrees. Secondly, due to the mixed views of the effects of water sources, it aims to investigate whether the perception of noise at home is moderated by visibility of sea, and how the moderation impact of the water source is compared to that of greenery. Finally, it also aims to examine whether the noise annoyance moderation effects of sea and greenery views vary with an individual's personal characteristics.

3.2 Organization of this chapter

In order to achieve the aims of this chapter, two separate studies, Study I and Study II, were carried out. Study I mainly investigates the effect of different types of settings and different amount of greenery on noise annoyance perception. Three residential estates were selected in Hong Kong such that the effects of different types of setting and amount of greenery can be investigated.

Study II extends the scope of Study I by evaluating the effect of both greenery and sea concurrently. In addition, Study II also investigates whether noise annoyance moderation effects of sea and greenery views vary with any individual personal characteristics. One of the three previously studied estates was selected for in-depth investigation as some of the residents from the site were expected to be able to perceive a greenery view, a sea view or both.

3.3 Methodology for Study I

3.3.1 Site Selection

In order to study the effect of respondent's perception of greenery on noise annoyance, target respondents were randomly selected from residential estates in Hong Kong. As we would like to limit the total number of the target survey respondents to meet our resources constraint, we attempted to control the range of values for the factors influencing the annoyance ratings. Accordingly, we have defined the following three criteria in the selection of our estates. Firstly, the ambient noise levels in the three estates should be lying within a narrow range, and road traffic should be their major noise sources. Secondly, the demographic characteristics of the residents living within the studied estates should be comparable. Estates with similar pricing levels for their apartments should be selected based on an underlying premise that the apartment pricing level is a proxy for demographic characteristics of its residents. Finally, greenery should be located in close vicinity of the examined estates and can be perceived by some but not all of their residents. The setting of surrounding greenery should be different for the three examined estates.

As a result, two estates located in Tin Shui Wai (TSW) and the other one located in Tsuen Wan (TW) in Hong Kong were selected as our studied sites. Estate TSW1 (Chestwood Court), which is situated in Tin Shui Wai district, is located adjacent to the Tin Shui Wai Park. The Park, which is located at the heart of New Town in Tin Shui Wai, has a total area of 14.8 hectares. It provides a spacious leisure and recreational area for the enjoyment of the public. Estate TSW2 (Grandeur Terrace) is also situated in Tin Shui Wai district but is located adjacent to the Hong Kong Wetland Reserve Park. The Wetland Park is about 61 hectares in size, which is a man-made wetland recreating habitats specially designed for waterfowls and other wildlife. On the other hand, Estate TW1 (Belvedere Garden) is situated in Tsuen Wan district, and some of its apartments were facing a grassy hill in proximity to the Tuen Mun highway. Figures 3.1a, 3.1b and 3.1c show the neighborhood maps for TSW1, TSW2 and TW1 respectively, while Figures 3.2a, 3.2b and 3.2c show the scenery views surrounding the respective estates.

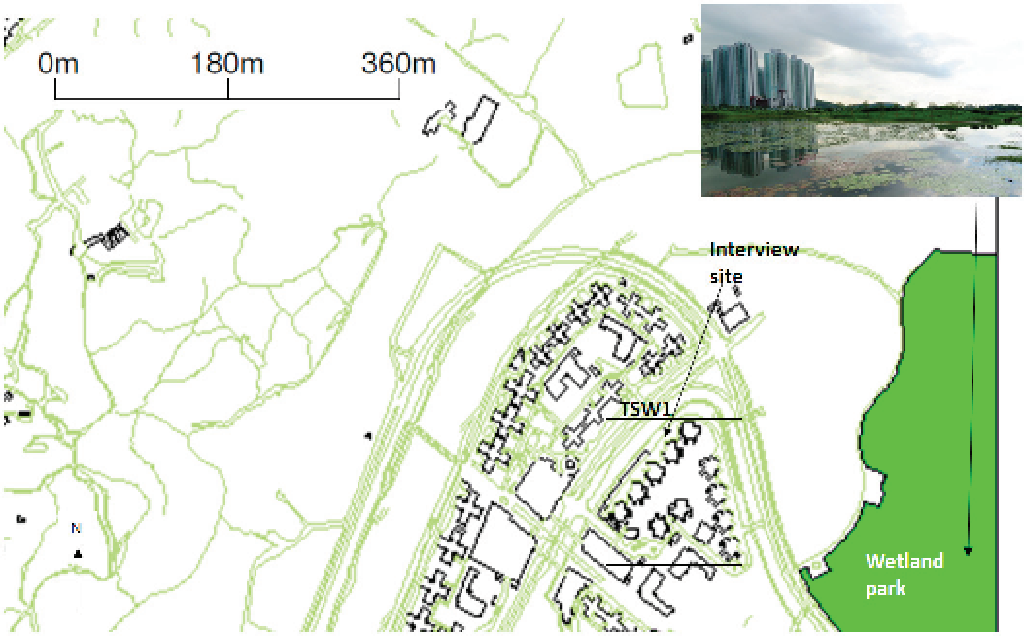

Figure 3.2a The neighborhood map for TSW1

Figure 3.2b The neighborhood map for TSW2

Figure 3.2c The neighborhood map for TW1

Figure 3.3a Wetland Park near Estate TSW1

Figure 3.3b Tin Shui Wai Park in front of Estate TSW2

Figure 3.3c Grassy hill near Estate TW1

Meanwhile, respondents were requested to report the amount of greenery that could be perceived from their homes on a three-point scale (0-2 graded; ‘0’ stands for no perception of greenery, ‘1’ stands for perception of a little greenery, and ’2’ stands for perception of a lot of greenery).

Also, each respondent was requested to provide information on the orientation of his/her home and the floor level on which the home resided. With all this information, Calculation of Road Traffic Noise (CRTN) method (Department of Transport, 1988) was applied to predict the noise levels at the façades of the respondents’ homes. The site dependent constants appeared in the CRTN method were derived from site measurements conducted at both the ground and roof levels of each examined estate. CRTN has been widely applied worldwide to predict noise level on a building façade due to traffic sources in socio-acoustic surveys when the access to residential home is not possible (e.g. Job et al., 2001; and Miedema and Vos, 1998). CRTN estimates traffic noise level mainly based on the distance of the receiver point from the road, the traffic volume on the road concerned, the average vehicle speed, and the light-to-heavy vehicle ratio. With a simple road-façade system in Hong Kong, the standard error of applying CRTN for prediction was determined to be within 2 dB (Tang and Tong, 2004).

Four Brüel & Kjær sound level meters (2 Type 2238F and 2 Type 2260B) were used for measuring the equivalent sound pressure levels (L_{Aeq}) and the percentile levels L_{A10} and L_{A90} in the present study. These four meters were divided into two groups and each group consisted of one Type 2238F and one Type 2260B meter. During each measurement, each group of meters was set in a particular orientation with the Type 2238F meter at the roof-top and the Type 2260B meter at the podium level. All the microphones were fixed at 1 m away from the roof-top façade or the podium boundary wall. Each measurement lasted for 30 minutes and the measurement orientations were changed after each measurement. Noise measurements were carried out between 10:00 to 17:00 on sunny days.

The traffic parameters associated with the CRTN prediction model for computing the concerned road noise levels were recorded using video cameras at the same time when the noise measurements were carried out. These data enabled necessary noise level corrections to be made to reflect the worst scenario situation under the CRTN framework.

The noise levels at the respondents' home façades were estimated using the distance correction formula depicted in the CRTN model and the measured podium level noise levels (in the right orientation). Path difference correction formula was also utilized to take into account the noise screening effect caused by podium walls. The path difference correction for the worst case, which occurred at the lowest receiver point, was less than 1 dB(A). The measured roof-top noise levels were also used in such prediction separately, but the difference between the two predictions are in general within 2 dB(A), which is within the range of the CRTN prediction accuracy. The predictions using podium level noise levels were adopted in the foregoing statistical analysis.

Nevertheless, with regard to the complex road geometry and building morphology in Hong Kong, the noise data collected was treated with cautions. In case the noise level measured at roof-top level was higher than that at podium level, CRTN prediction might not be applied and the corresponding survey data would be discarded.

3.3.2 Data collection

Survey was designed to collect data for formulating a quantitative model to examine the noise annoyance responses at homes. Researchers and student helpers were recruited and trained to conduct the survey. The surveys were conducted between 10:00 a.m. and 4:00 p.m. on consecutive Saturdays and Sundays. During the surveys, respondents were randomly approached on the footpaths near the main road around the residential estate as shown in Figure 3.2a, 3.2b, and 3.2c, and were invited for the survey if they had indicated that they were residents. Respondents agreed to participate in the survey were instructed to mark their responses.

The randomness of the sample was maintained by randomly approaching respondents around the survey sites. However, children were not invited for the survey in order to ensure the validity of the data. Responses collected from respondents who were not living in the studied sites were excluded from the analysis.

Questionnaire used in this study comprising two major sections. The first section aimed at eliciting from respondents their annoyance responses to road traffic noises at homes over the past twelve months. Both five-point verbal scale and eleven-point numerical scale recommended by ISO standard 15666 (2003) were employed for revealing the noise annoyance rating assigned by individuals at their homes. The contents of the ‘show card’ for the annoyance scales as suggested in ISO standard 15666 (2003) were also presented to respondents, even though not in a card format. Using both scales simultaneously can enhance the reliability of the results by providing opportunities for counterchecking the alignment of the responses on the two scales (Klæboe et al., 2003). The five-point verbal scale contains five different annoyance ratings, namely ‘Not at all’, ‘Slightly’, ‘Moderately’, ‘Very’ and ‘Extremely’. On the other hand, 11-point scale (0-10 graded; ‘0’ stands for ‘Not at all’ and ‘10’ stands for ‘Extremely’) was also used as it can generally be more readily understood and manipulated by respondents than other types of scales.

Besides, respondents were asked to rate to what degree (i) air pollution and obnoxious smells, (ii) dust and dirt, and (iii) vibrations and tremors also annoyed them at their homes in the past twelve months. These three agents are included with an objective to remind respondents of other problems besides annoyance brought about by noise (Bjørner et al., 2003). To shorten the length of the questionnaire form, only five-point scales were employed for eliciting respondents’ annoyance responses to these three agents.

The second section of the questionnaire contains seventeen questions aiming at revealing respondent’s personal characteristics, like age, education level, self-rated noise sensitivity and health status, including these questions can facilitate the subsequent analysis of the effects of personal characteristics on the annoyance rating. Although there is a complex meaning for the term ‘noise sensitivity’ in the theoretical literature, a simple five-point verbal scale was used to elicit from lay respondents their noise sensitivity. Respondents were also inquired about the amount of greenery that could be perceived from their homes (see the extract of the survey questionnaire shown in Appendix A for more details).

3.4 Results and discussion for Study I

Prior to the full-scale surveys, a trial run was conducted in September 2008 with an objective to remove any ambiguities on the content of the questionnaire design and on the method of delivering the survey. A full-scale survey was undertaken between October 2008 and October 2009. Nine hundred and ninety-two responses were successfully collected, and 688 of which had provided adequate information for enabling a more accurate prediction of their home noise levels.

3.4.1 Respondents' personal characteristics

Table 3.1 summarizes the personal and dwelling characteristics of all our survey respondents. More than half of the respondents were over 40 years old. About half had only received elementary or high school education. More than half had a monthly income level of lower than HK$20,000. This is reasonable as all the examined estates were located in relatively deprived areas, and the average income levels of their residents fell within the lowest quartile of Hong Kong population.

Table 3.1
Summary of personal and dwelling characteristics of the respondents

Description		**Estate**		**Total**
	TSW1	**TSW2**	**TW1**	
Gender				
Male	120 (59%)	104 (47%)	117 (45%)	341 (50%)
Female	85 (41%)	117 (53%)	145 (55%)	347 (50%)
Age				
≤29	3 (1%)	21 (10%)	35 (13%)	59 (9%)
30-39	83 (40%)	74 (33%)	75 (29%)	232 (34%)
40-49	80 (39%)	87 (39%)	88 (34%)	255(37%)
50-59	21 (10%)	27 (12%)	48 (18%)	96 (14%)
≥60	18 (10%)	12 (6%)	16 (6%)	46 (6%)

Education attainment				
Elementary and High School	107 (52%)	119 (54%)	129 (49%)	355 (52%)
College or above	98 (48%)	102 (46%)	133 (51%)	333 (48%)
Monthly income (HK$) *				
≤4999	28 (14%)	11 (5%)	29 (11%)	68 (10%)
5000-9999	44 (21%)	54 (24%)	66 (25%)	164 (24%)
10000-19999	54 (26%)	51 (23%)	52 (20%)	157 (23%)
20000-29999	21 (10%)	32 (14%)	36 (14%)	89 (13%)
30000-39999	6 (3%)	17 (8%)	16 (6%)	39 (6%)
≥40000	0 (0%)	17 (8%)	12 (5%)	29 (4%)
Home noise levels in dB(A) (standard deviation)	50.7 - 65.0 (4.5)	45.6 - 72.0 (6.2)	59.6 - 69.5 (2.5)	45.6 – 72.0 (5.8)
Total number of respondents	205	221	262	688

*Total does not sum up to 100% as some respondents refused to reveal their respondent income level

Table 3.1 also shows a breakdown in the demographic characteristics (i.e. gender, age, education level and respondent income) by percentage for the respondents surveyed in the three estates. Broadly speaking, the demographic characteristics of the survey respondents are found to be similar among the three groups despite a slightly higher proportion of male are found within the TSW1 group. The average monthly income of the respondent from this group was found to be slightly lower than the other groups. Table 3.2 shows a breakdown by counts of respondents who could perceive different amount of greenery in different estates.

The noise levels at 1m outside the façade of individuals' respondent's homes were predicted using the CRTN method with its constants values being derived from our site measurement data. The predicted noise levels corresponding to the A-weighted equivalent noise exposure (L_{Aeq}) for the peak hour during day time, and were used to correlate with the noise annoyance rating reported by respondents according to the worst situation in day time. Figure 3.4 shows the frequency distribution for different ranges of noise levels predicted for the respondents' homes. A majority of the background traffic noise levels of the studied homes lie within a range of 50 – 70 dB(A) and a peak occurs at 65 dB(A) level. This is in agreement with the daytime local statutory noise control standard for sub-urban development (EPD, 1990).

Table 3.2
Breakdown by counts of the respondents who could perceive different amount of greenery in different estates

Amount of greenery perceived	TSW1	TSW2	TW1
No greenery	28	52	47
Little greenery	143	150	193
A lot of greenery	34	19	22
Total	205	221	262

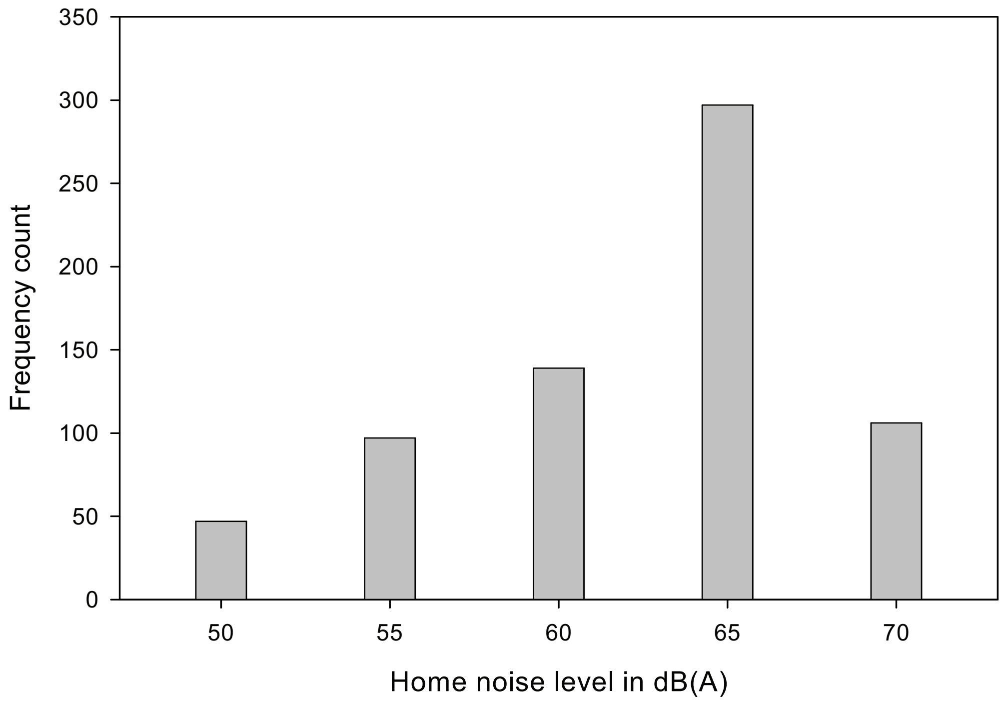

Figure 3.4 Frequency distribution for different ranges of home noise levels (grouped in 5 dB(A) intervals)

Besides noise, respondents were also asked to assign an annoyance rating to other agents, like obnoxious smells, dust and sound vibration, arisen from road traffic on 5-point verbal scales. As seen in Table 3.3, respondents were significantly more concerned with the problems brought about by noise annoyance, obnoxious and dust than those brought about by sound vibration ($p<0.05$ by independent t-tests). Obnoxious smell and sound vibration did not have any significant correlation with the noise annoyance rating at home (not significant at 0.05 level). Conversely, dust is only agent which is determined to be correlated, even though it is only weakly correlated, with noise annoyance rating at home on the 5-point scales (bivariate correlation = 0.084, significant at 0.05 level).

Table 3.3
Annoyance Ratings in relation to the Agents Associated with Road Traffic (n=688)

	Home noise annoyance		**Obnoxious Smell**	**Dust**	**Sound Vibration**
	10-point scale	5-point scale			
Range	0-10	1-5	1-5	1-5	1-5
Average	3.81	2.47‡	2.45‡	2.95‡	1.47‡
Standard deviation	1.97	0.81	0.94	0.89	0.74
Strength of correlation with home annoyance rating (on 5-point scales)	N/A	N/A	0.021	0.084*	0.037

*Significant at 0.05 level
‡ Significant difference between noise annoyance rating and sound vibration, between obnoxious smell and sound vibration, and between dust and sound vibration at 0.05 level.

3.4.2 Model for predicting the annoyance ratings

Data collected from these 688 interviews was used for formulating an ordered logit model, which has the following functional form:

$$Z_i = \sum_i \beta_i x_i + \varepsilon_i = M_i + N_i + \varepsilon_i \tag{3.1}$$

where β_i represent the coefficient estimates for parameters X_i like age, education level, gender, income level, self-rated sensitivity, self-rated health status, perceived amount of greenery, and noise level expressed in terms of NOISE (dB(A)) at the respondents' homes. M_i is a set of personally related characteristics. N_i is a set of neighborhood characteristics. In this study, the responses on the 11-point scale were used in our model development as the equal spacing numerical scale better fits the basic assumption for regression models (Fields et al., 2001). Besides, errors arisen from insufficient variation in responses are observed if the responses on the 5-point scales are used in our prior model formulation.

Ordered logit model was chosen to model the annoyance responses collected during the survey as the output of the logistic function is always confined to values between 0 and 1. It can be used to represent the probability of a particular outcome, i.e. the probability of assigning a low annoyance rating. Ordered logistic regression is basically a form of regression which exists to handle the case for which the dependent variable has classes more than two and is not continuous in nature. The ordered nature of the regression model fits our need in modelling the annoyance responses from respondents as the annoyance responses were collected using an ordinal 11-point scale which is discrete (not continuous) in nature.

Ordered logistic regression can be used to determine the percent of variance in the dependent variable that can be explained by the independents. Of particular, the logit estimates can be used to rank the relative importance of independents. The independents can be of any types such as ordered category and continuous category and the values of any independent variable can be ranged from negative infinity to positive infinity. This caters for the analysis of socioeconomic variables which are ordered in nature and acoustical variable which are continuous in nature.

Table 3.4
Coefficient estimates for the ordered logit model portraying the annoyance-dB relationship

Model fitting information		
Log likelihood function	-1205.27	
McFadden's ρ^2	0.14	

Attribute	**Coefficient *β* Standardized Value Listed in Parenthesis**	***p*-value**
Index function for probability		
Constant	0.521	0.343
NOISE	0.051(0.091)	0.000*
AGE	0.201(0.063)	0.000*
EDU	0.305 (0.072)	0.000*
GENDER	0.038	0.646
IND_INCOME	0.000	0.225
SENSITIVITY	-0.270(0.078)	0.000*
HEALTH	-0.339(0.087)	0.000*
Y_{g1i} †	-0.887	0.000*
Y_{g2i} †	-1.117	0.000*
Y_{g3i} †	1.047	0.000*
Y_{g4i} †	-0.970	0.000*
Y_{g5i} †	1.022	0.000*
Y_{g6i} †	-0.164	0.480
Threshold parameters for index		
μ_1	0.000	N.A.
μ_2	0.571	0.000*
μ_3	1.696	0.000*
μ_4	2.505	0.000*
μ_5	3.009	0.000*
μ_6	3.644	0.000*
μ_7	4.118	0.000*
μ_8	4.744	0.000*
μ_9	5.624	0.000*
μ_{10}	6.143	0.000*

* significant at 0.01 level
† special codings assigned to different types of setting and perceived amount of greenery

3.4.3 Validity of the constructed ordered logit model

McFadden's ρ^2 is used to evaluate the goodness of fit of the multivariate model. McFadden's ρ^2 is analogous to R-square commonly applied in linear regression in that the log likelihood of the intercept model can be regarded as the total sum of squares while the log likelihood of the full model can be regarded as the sum of square errors. Table 3.4 lists the results of the constructed ordered logit model. The model gives a McFadden's ρ^2 value of 0.14. This suggests that the model can reasonably fit for our response data, and is valid for portraying the effects of the examined factors on the rated noise annoyance of the surveyed respondents.

3.4.4 Identification of modifiers for annoyance and determination of their effects

Conceivably, the annoyance ratings assigned for homes are found to be influenced by the background noise levels. At the first glance, the coefficient estimate, and hence the effect size, for noise level experienced by residents at home is relatively small. As different factors have different units of scales, standardization of the respective coefficient values is needed before a logical comparison can be made. From Table 3.4, the standardized value of noise level (as shown in the parenthesis) is the highest as compared with those of the other significant personal factors like age, education level, noise sensitivity and health status. This is in line with the findings revealed by Jakovljevic et al. (2009) and Paunović et al. (2009).

However, it should be noted that an individual's personal characteristics also play a role in the moderation of noise annoyance perception. Results shown in Table 3.4 suggest that individual's age, education level, noise sensitivity, health status, and perceived amount of greenery tend to moderate the noise annoyance rating at his home. Generally, older respondents tend to feel more annoyed. Conversely, respondents reporting lower noise sensitivity or better health status felt less annoyed.

3.4.5 The effects of setting and perceived amount of greenery on noise annoyance perception

All the response data were segmented according to different types of greenery setting and different amount of greenery in order to investigate their effects on noise annoyance. Specific dummy codings were applied in our model to differentiate different types of setting and perceived amount of greenery. This is a standard procedure recommended for econometric regression analysis in handling qualitative and categorical variables (Hill et al, 2001). Seven categories of greeneries are created – namely *No greenery*, A *little greenery from garden and park in TSW1*, *A lot of greenery from garden and park in TSW1*, *A little greenery from garden and park in TSW2*, *A lot of greenery from garden and park in TSW2*, *A little greenery from grassy hills in TW1*, and *A lot of greenery from grassy hills in TW1*). With seven categories, only six dummy variables, Y_{g1i}, Y_{g2i}, Y_{g3i}, Y_{g4i}, Y_{g5i} and Y_{g6i}, are needed with all their codes being listed in Table 3.5.

Table 3.5
Estimated coefficients for different types of greenery setting and different amount of greenery

Amount of Perceived Greenery and Type of Setting of Greenery	Special codings assigned to different types of setting and perceived amount of greenery						Final coefficient value
	Y_{g1i}	Y_{g2i}	Y_{g3i}	Y_{g4i}	Y_{g5i}	Y_{g6i}	
No greenery (level 0)	0	0	0	0	0	0	0
A little greenery, garden and park, (level 1 in TSW1)	1	0	0	0	0	0	-0.887
A lot of greenery, garden and park (level 2 in TSW1)	1	1	0	0	0	0	-2.004
A little greenery, garden and park (level 1 in TSW2)	1	1	1	0	0	0	-0.957
A lot of greenery, garden and park (level 2 in TSW2)	1	1	1	1	0	0	-1.927
A little greenery, grassy hill (level 1 in TW1)	1	1	1	1	1	0	-0.905
A lot of greenery, grassy hill (level 2 in TW1)	1	1	1	1	1	1	-0.905

With the foregoing segmentation, Model (3.1) becomes

$$Z_i = M_i + \beta_{g1} Y_{g1i} + \beta_{g2} Y_{g2i} + \beta_{g3} Y_{g3i} + \beta_{g4} Y_{g4i} + \beta_{g5} Y_{g5i} + \beta_{g6} Y_{g6i} + \varepsilon_i \qquad (3.2)$$

where Y_{g1i}, Y_{g2i}, Y_{g3i}, Y_{g4i}, Y_{g5i} and Y_{g6i} are the dummy variables used for portraying different types of setting and different amount of greenery perceived.

Under our coding arrangement, the coefficient values of different categories of greenery, unlike those of personal characteristics, cannot be directly read off from Table 3.4 but are needed to be further synthesized from the coefficient values of *Y* before the noise annoyance moderation effects for different categories of greenery can be revealed. For instance, the coefficient value of 'a lot of greenery in garden and park in TSW1' is equal to the summation of values of Y_{g1i} and Y_{g2i}. Furthermore, it is observed from Table 3.4 that all the Y values, except for Y_{g6i} value**,** are determined to be significant at 0.05 level. This implies that the values of Y_{g1i}, Y_{g2i}, Y_{g3i}, Y_{g4i} and Y_{g5i} shown in Table 3.4 are statistically significant and are equal to the values shown in Table 3.4. By contrast, the value of Y_{g6i} is equal to zero due to its statistical insignificancy.

Table 3.5 lists the resulting coefficient values estimated by the ordered logit model for 7 different categories of greenery. All the final coefficient values of greenery are found to be negative compared with that of no greenery. This implies that probabilities of causing higher noise annoyance are smaller as a result of the existence of different types of greenery setting and different amount of greenery perceived. This led us conclude that the existence of gardens and parks, or grassy hills in the surroundings does play an important role in moderating the noise annoyance ratings assigned by respondents at their homes. However, accessibility to nearby greenery does not seem to be a critical factor for lowering noise annoyance ratings at homes as all the greeneries are located adjacent to the studied estates and are also easily accessible by the estate residents. This is somewhat different from what was suggested by Gidlöf-Gunnarsson & Öhrström (2007) that accessibility to greenery could reduce noise annoyance at homes.

On the other hand, the type of greenery setting exerts a significant effect on moderating noise annoyance. The size of moderation effects on noise annoyance due to perception of different amount of greenery is dependent on the type of greenery setting to which individuals perceived from their homes. In case individuals' homes are located in proximity to wetland parks or garden parks, those perceiving a lot of greenery feel less annoyed than those perceiving only a little greenery (i.e. -0.887 vs -2.004 in TSW1 and -0.957 vs -1.927 in TSW2 for the corresponding final coefficient values listed in Table 3.5). In case where the homes are located in proximity to grassy hills, those perceiving a lot of greenery assigned similar annoyance ratings with those perceiving only a little greenery (i.e. -0.905 vs -0.905 in TW1 for the corresponding final coefficient values listed in Table 3.5).

3.5 Methodology for Study II

3.5.1 Studied sites

Estate TW1 (Belvedere Garden), which is situated in Tsuen Wan district, has been chosen as the studied site for Study II since the residents from this estate may be able to perceive a greenery view or a sea view or both. Surveys were conducted extensively in this estate in order to examine whether a sea view would increase the likelihood in moderating respondent's annoyance response at home, and whether respondent's personal characteristics would have impacts on his annoyance response.

Figure 3.2c shows the neighborhood map of this studied site. It can be seen from Figure 3.2c that the sea is situated at the south direction of the estate. Grassy hills, which are the major type of greenery that can be perceived by some of the residents in the studied estate, are mainly situated at the west and north direction of the estate. Residents from this targeted estate were randomly approached for interviews. The information of apartment orientation and floor level collected from respondents during surveys were used to predict the background noise levels respondents were exposed to at their homes by means of CRTN method.

3.5.2 Survey instrument

Similar to the questionnaire used in Study I, the questionnaire also comprises two major sections. The first section contains both an eleven-point numerical scale and a five-point verbal scale question for eliciting from respondents the annoyance ratings at their homes. The 11-point scale contains eleven annoyance ratings (0-10 graded; ‘0’ stands for ‘Not at all’ and ‘10’ stands for ‘Extremely’).

The second section aims at collecting information on individuals’ personal characteristics. A five-point scale (1-5 graded; ‘1’ stands for ‘very sensitive’ and ‘5’ stands for ‘not sensitive at all’) was used for respondents to report the levels of noise sensitivity themselves. Also, a five-point scale (1-5 graded; ‘1’ stands for ‘very bad’ and ‘5’ stands for ‘very good’) was utilized for respondents to report their current health conditions. An additional question on the duration of time spent at home daily was also included with a four-point scale (1-4 graded; ‘1’ stands for ‘less than 6 hours’, ‘2’ stands for ‘between 6 and 12 hours’, ‘3’ stands for ‘between 12 and 18 hours’, and ‘4’ stands for ‘more than 18 hours’) for analyzing the effect of duration of time spent at homes on individuals’ noise perception.

Respondents were requested to report whether they had any sea views at homes on a dichotomous scale (0-1 graded; ‘0’ stands for ‘no’ and ‘1’ stands for ‘yes’). Meanwhile, they were also requested to report the amount of greenery vegetation to which they were exposed from their homes on a three-point scale (0-2 graded; ‘0’ stands for ‘no greenery vegetation’, ‘1’ stands for ‘a little greenery vegetation’, and ‘2’ stands for ‘plenty of greenery vegetation’).

The data collected on these scales were then used for formulating dichotomized scales to facilitate later multivariate analysis. The dichotomized scale for age, time spent at home and level of education attainment were formulated based on 50-percentile value of the respondents’ population. For example, the respondents were dichotomized into two age groups (one above and equal to 40, and one below 40). Table 3.6 shows a set of dichotomized codings assigned for the multivariate analysis.

Besides sea and greenery views, each respondent was also requested to provide information on the orientation of his/her home and the floor level on which his/her home resided. The extract of the survey questionnaire can be found in Appendix B (the data collected in Part 2 & Part 3 of this questionnaire are employed for the analysis in Chapter 4).

Data collected during the survey were used to formulate an ordered logit model for further analysis. A logit function can be derived from the ordered logit model estimates and used to predict the probability for an individual to assign a particular annoyance rating. The probability of assigning a particular annoyance rating can be estimated as follows:

$$Y^*_i = \frac{1}{1 + \exp(Z_i - \mu_y)} \tag{3.3}$$

where Z_i assumes different value at different sound pressure level i, μ_y is the threshold value for annoyance rating y estimated for the ordered logit model and y ranges from 1 to 10. The dependent variable Z_i is assumed to be a linear additive function of the independent variable x_i:

$$Z_i = \sum_i \beta_i x_i + \varepsilon_i \tag{3.4}$$

where β_i is the coefficient pertaining to x_i.

Eqn (3.3) can be used to estimate the probability for an individual to assign a specific annoyance rating (i.e. 0, 1, 2, etc.) if the values of the variables listed in Eqn (3.4) are known. For the interests of this study, it would be meaningful to estimate the probabilities of giving a low annoyance response, i.e. an annoyance rating of lower than or equal to 4 by summing up the individual probabilities for assigning an annoyance rating from 0 to 4. The probabilities can be used to compute the odds ratio for giving a low annoyance response under a specific condition according to Eqn (3.5).

$$Oddsratio = \frac{\frac{p_1}{1 - p_1}}{\frac{p_2}{1 - p_2}} \tag{3.5}$$

where p_1 and p_2 represent the probabilities for assigning a low annoyance response for the particular groups to be compared

3.6 Results and discussion for Study II

Prior to full-scale surveys, a trial run was conducted in September 2008 with an objective to remove any ambiguities arisen from both the content of the questionnaire design and the method of delivering the survey. A full-scale survey was undertaken between October 2008 and February 2010. Passers-by were randomly approached in the studied estate and invited for interviews. One-thousand two-hundred and five face-to-face interviews were successfully administered, and eight hundred and sixty-one of which had provided adequate information for predicting the noise levels at the façade outside homes.

Table 3.6
Summary statistics of individuals' personal and dwelling characteristics of the respondents and their assigned codings in the ordered logit model

Description	Number of Counts	Assigned codings
GENDER (gender)		
Male	394 (46%)	0
Female	467 (54%)	1
AGE (age)		
≤29	97 (11%)	0
30-39	241 (28%)	0
40-49	284 (33%)	1
50-59	179 (21%)	1
≥60	60 (7%)	1
MARRIAGE (marital status)		
Not married	136 (16%)	0
Married and others	725 (84%)	1
EDU (education level)		
Elementary and High School	440 (51%)	1
College or above	421 (49%)	0

SENSITIVITY (noise sensitivity)		
Very sensitive	80 (9%)	0
Quite sensitive	262 (30%)	0
Average	369 (43%)	0
Not quite sensitive	102(12%)	1
Not sensitive at all	48 (6%)	1
HEALTH (self-reported health status)		
Very bad	38 (4%)	0
Bad	154 (18%)	0
Average	386 (45%)	0
Good	213(25%)	1
Very good	70 (8%)	1
TIME (Daily time spent at home)		
Less than 6 hours	297 (34%)	0
Between 6 and 12 hours	438 (51%)	1
Between 12and 18 hours	112 (13%)	1
More than 18 hours	14 (2%)	1
GREEN1 (a little greenery view)		
Not being exposed	233 (27%)	0
Being exposed	628 (73%)[a]	1
GREEN2 (plenty of greenery view)		
Not being exposed	809 (94%)	0
Being exposed	52 (6%)[b]	1
SEA (sea view)		
Not being exposed	353 (41%)	0
Being exposed	508 (59%)	1
Occupation		
Self-employed	102 (12%)	N/A
Employed	522 (61%)	N/A
Student	7 (1%)	N/A
Housewife	117 (14%)	N/A
Retired	69 (8%)	N/A
Others	24 (3%)	N/A
Noise levels at homes	55.4 – 69.5 dB(A)[c]	N/A[d]

Total number of respondents	861	N/A

*Total does not add up to 100% as some respondents refused to reveal their occupation
[a] Three hundred and eighty-eight of these respondents were also exposed to a sea view at the same time
[b] Twenty of these respondents also were exposed to a sea view at the same time
[c] dB(A) levels at respondents' homes, which are the energy-equivalent levels based on the thirty-minute measurements inside the residential buildings predicted using the CRTN model

3.6.1 Respondents' backgrounds

Table 3.6 shows the personal and dwelling characteristics of all the respondents. Sixty-one percent of the respondents were over 40 years old. Nearly half of the respondents had received elementary or high school education. Sixty-one percent of the respondents were employed and 12% were self-employed. Only a small percentage of the respondents were housewives (14%) or retirees (8%). Of the 861 surveyed respondents, 240 of whom had a little greenery view at homes, 32 had plenty of greenery view, and 100 had a sea view. Three hundred eighty-eight respondents had a little greenery view and a sea view at homes, while 20 had plenty of greenery view and a sea view at homes. The remaining 81 respondents did not have any sea or greenery view. Table 3.7 summarizes the number of respondents perceiving greenery views and sea views. The noise level at 1m outside the façade of individual respondent's home was predicted to be lying within a range of 55-70 dB(A).

Table 3.7
Summary of respondents perceiving greenery view and sea view

Respondent group	**Number of respondents**
Perceiving little greenery view only	240
Perceiving plenty of greenery view only	32
Perceiving sea view only	100
Perceiving little greenery view and sea view	388
Perceiving plenty of greenery view and sea view	20
Not perceiving any greenery view and sea view	81
Total	861

3.6.2 Annoyance responses

Figure 3.5 shows a breakdown by counts of individuals assigning different annoyance ratings at their homes. The frequency profile for the assigned annoyance ratings generally follows a normal distribution but slightly skews towards the lower end. A relatively small proportion of the respondents (24%) reported they were either not annoyed (i.e. with an annoyance rating of 2 or below) or highly annoyed (i.e. with an annoyance rating of 9 or above). Sixty-two percent of the respondents reported to be slightly or moderately annoyed (i.e. with an annoyance rating of 3, 4, 5 or 6), and about 27% reported their annoyance ratings to be below 3 on an 11-point scale. Table 3.6

shows a breakdown by counts of individuals who had sea views or different types of greenery views at homes.

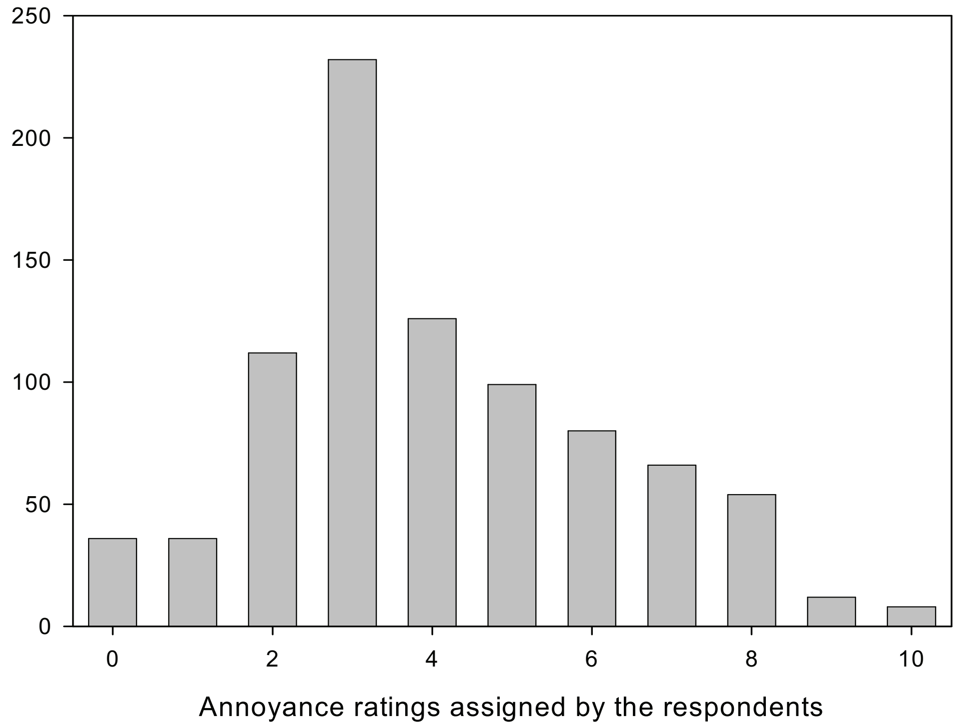

Figure 3.5 Breakdown by counts of respondents assigning different annoyance ratings

3.6.3 Effect of greenery and sea view on noise annoyance perception

Responses collected during surveys were employed for constructing the following ordered logit function:

$$
\begin{aligned}
Z_i &= \sum_i \beta_i x_i + \varepsilon_i \\
&= \beta_{NOISE}\, NOISE + \beta_{AGE}\, AGE + \beta_{EDU}\, EDU + \beta_{GENDER}\, GENDER \\
&+ \beta_{MARRIAGE}\, MARRIAGE + \beta_{HEALTH}\, HEALTH + \beta_{SENSIVITY}\, SENSITIVITY \\
&+ \beta_{TIME}\, TIME + \beta_{SEA}\, SEA + \beta_{GREEN\,1} GREEN\,1 + \beta_{GREEN\,2} GREEN\,2 + \varepsilon_i
\end{aligned} \tag{3.6}
$$

where and β_i s represent the coefficient estimates for factors X_i; *NOISE* represents noise level at the respondents' homes (expressed in terms of $dB_{Leq}(A)$), *AGE* represents the age group into which the respondents fall, *EDU* represents education level, *GENDER* represents gender, *MARRIAGE* represents marital status, *HEALTH* represents self-rated health status, *SENSTIVITY* represents self-rated auditory sensitivity, *TIME* represents duration of time spent at home, *SEA* represents sea views, *GREEN1* and *GREEN2* are dummy codings used for representing different amount of greenery views to which the respondents' homes were exposed.

GREEN1 refers to visibility of a little greenery view at home and *GREEN2* refers to visibility of plenty of greenery views at home. All the response data were segmented according to different amount of greenery views to which the respondents' homes were exposed in order to investigate whether different amount of greenery would lower the annoyance ratings to different degrees.

Data would be discarded if respondents failed to provide all the necessary information. Consequently, 861 valid responses are used in our final model formulation. The attribute levels and codings assigned for the studied factors in our model development are shown in the last column of Table 3.6.

As the constructed ordered logit model can reasonably fit the data, it can be used to portray the annoyance responses (with a McFadden's ρ^2 value of 0.17). Table 3.8 lists the coefficient values estimated for various factors. The sign for the coefficient indicates the relationship between the examined factor and the annoyance rating. The signs determined for the various factors are in line with our priori expectations. For example, a positive coefficient for age suggests that the annoyance rating increases with age of the respondent. Meanwhile, a negative coefficient for noise sensitivity suggests that the annoyance rating will be lowered if the respondent is considered himself to be 'not noise sensitive at all' instead of 'very noise sensitive'. The coefficient for the variable *NOISE* indicates the rate of change in annoyance rating with respect to a change of 1 dB(A) noise level. The positive coefficient suggests a higher annoyance rating for an increment in noise level.

Table 3.8
Coefficient estimates for the ordered logit model portraying the annoyance-response relationship at respondents' homes

Model fitting information			
Number of observations			861
Log likelihood function			-1513.304
McFadden's ρ^2			0.17
Attribute	**Coefficient (β)**	***p*-value**	**Odds ratio**
Index function for probability			
Constant	-1.588	0.109	N.A.
NOISE	0.061	0.000*	N.A.
AGE	0.543	0.000*	1.72[a]
EDU	-0.313	0.000*	1.37[b]
GENDER	0.042	0.612	N.A.
MARRIAGE	-0.071	0.369	N.A.
HEALTH	-0.320	0.000*	1.38[c]
SENSITIVITY	-0.485	0.000*	1.62[d]
TIME	-1.408	0.000*	4.09[e]
SEA	-0.919	0.054*	2.51[f]
GREEN1 (a Little)	-1.738	0.000*	5.69[g]
GREEN2 (Plenty)	-1.911	0.000*	6.76[g]
Threshold parameters for index			
μ_1	0.000	0.000*	N.A.

μ_2	0.444	0.000*	N.A.
μ_3	1.214	0.000*	N.A.
μ_4	2.244	0.000*	N.A.
μ_5	2.776	0.000*	N.A.
μ_6	3.245	0.000*	N.A.
μ_7	3.756	0.000*	N.A.
μ_8	4.445	0.000*	N.A.
μ_9	5.534	0.000*	N.A.
μ_{10}	6.076	0.000*	N.A.

* Significant at 95% confident level
[a] Increase in risk if age of an individual is 'equal to or greater than 40'.
[b] Increase in risk if education attainment of an individual is 'college' or above.
[c] Increase in risk if an individual does not rate his health condition as 'good' or 'very good'.
[d] Increase in risk if an individual rates his noise sensitivity status as average, sensitive or very sensitive.
[e] Increase in risk if an individual spends less than half of a day at home.
[f] Increase in risk if an individual's home does not have any sea view.
[g] Increase in risk if an individual's home does not have any greenery view.

As expected, the likelihood in assigning a particular annoyance rating at home is influenced by many factors besides its background noise level. Age, education level, health status, noise sensitivity, duration of time spent at home, and greenery and sea view are found to influence the likelihood (i.e. significant at 0.05 levels). On the contrary, gender and marriage status are not found to alter the likelihood (i.e. insignificant at 0.05 levels).

3.6.4 Predicting the likelihood of assigning a low annoyance rating

Table 3.9
Chances for assigning low annoyance rating

Respondent group	**Probability of giving a low annoyance response**
(A) <u>An average individual</u>	
63 dB(A)	0.46
64 dB(A)	0.42
65 dB(A)	0.43
(B) <u>at 64 dB(A)</u>	

AGE (age)	
<39	0.49
≥40	0.37
EDU (education level)	
College or above	0.39
High school or below	0.46
HEALTH (self-reported health status)	
Average or below	0.39
Good or very good	0.46
SENSITIVITY(noise sensitivity)	
Very sensitive, sensitive or average	0.37
Not sensitive or not sensitive at all	0.49
TIME (daily time spent at home)	
Shorter stay (i.e. <12 hours daily)	0.27
Longer stay (i.e.≥12 hours daily)	0.60
GREEN1 (a little greenery view)	
No	0.23
Yes	0.65
GREEN2 (plenty of greenery view)	
No	0.23
Yes	0.69
SEA (sea view)	
No	0.30
Yes	0.55

* Probabilities of giving a low annoyance response (annoyance ratings of 0-4 from the 11-point scale) are derived to reveal the effectiveness of natural environment on reducing noise annoyance

Table 3.8 lists the model estimates for the developed ordered logit model. The estimate values can be used to predict the probabilities for giving a low annoyance response under a set of individual characteristics and noise level e.g. an average surveyed individual personal characteristics and average noise exposure level i.e. 64 dB(A). Table 3.9 shows the computed probabilities for individuals having different personal characteristics to give a low annoyance response. For instance, the probability for an average individual to give a low annoyance response at 63 dB(A) is 0.46, and drops to 0.44 at 64 dB(A) and further drops to 0.43 at 65 dB(A). This trend is in line with our expectation since the likelihood of assigning a lower annoyance rating decreases with an increase in the noise level at home.

On the other hand, the probabilities of giving low annoyance responses at 64 dB(A) were computed to be 0.49 and 0.37 for younger (aged below 40) and older individuals (aged above 40) respectively. There is a 49% and 37% chance that a younger individual and an older individual will give a low annoyance response respectively.

Further, there is a 60% chance that an individual will give a low annoyance response if he has a longer stay at home (i.e. spending more than 12 hours daily at home). The chance significantly lowers to 27% if an individual has a shorter stay at home (i.e. spending less than 12 hours at home). Moreover, there is a 55% chance that an individual having a sea view at home to give a low annoyance response and the probability of giving a low annoyance response will become higher if he has a greenery view at home (65% for a little greenery view and 69% for plenty of greenery view).

3.6.5 The effect of personal characteristics on annoyance moderation effect derived from perception of sea and greenery

A sea view or a greenery view can help relieve the noise annoyance problem. It is further hypothesized that the size of moderation effects varies with some personal characteristics. To further investigate this, we have segmented our data according to different personal characteristics. Eight interaction terms (*GREEN1 x AGE, GREEN2 x*

AGE, GREEN1 x Time, GREEN2 x Time, SEA x TIME, SEA x AGE, GREEN1 x SEA and *GREEN2 x SEA*) have been introduced in order to investigate whether there are any interaction effects between the perception of natural views and personal characteristics on noise annoyance perception. The final model form becomes:

$$\begin{aligned} Z_i = {} & \beta_{NOISE} NOISE + \beta_{AGE} AGE + \beta_{EDU} EDU + \beta_{GENDER} GENDER + \beta_{MARRIAGE} MARRIAGE \\ & + \beta_{HEALTH} HEALTH + \beta_{SENSIVITY} SENSITIVITY + \beta_{TIME} TIME + \beta_{SEA} SEA + \beta_{GREEN1} GREEN1 \\ & + \beta_{GREEN2} GREEN2 + \beta_{GREEN1xAGE} GREEN1xAGE + \beta_{GREEN2xAGE} GREEN2xAGE \\ & + \beta_{GREEN1xTIME} GREEN1xTIME + \beta_{GREEN2xTIME} GREEN2xTIME + \beta_{SEAxTIME} SEAxTIME \\ & + \beta_{SEAxAGE} SEAxAGE + \beta_{GREEN1xSEA} GREEN1xSEA + \beta_{GREEN2xSEA} GREEN2xSEA + \varepsilon_i \end{aligned} \tag{3.7}$$

Table 3.10 shows the logit coefficient estimates for the model shown in Eqn (3.7). Results from Table 3.10 suggest that an interaction effect exists between perception of greenery views and duration of time spent at home, and between perception of sea views and age of individuals. The values of the estimates can be used to estimate the impacts of an individual's personal characteristics on annoyance moderation.

Table 3.10
Coefficient estimates for the modified ordered logit model

Model fitting information		
Number of observations	861	
Log likelihood function	-1503.018	
McFadden's ρ^2	0.17	
Attribute	**Coefficient (β)**	***p*-value**
Index function for probability		
Constant	-0.124	0.896
NOISE	0.057	0.000*
AGE	0.464	0.000*
EDU	-0.289	0.000*
GENDER	0.055	0.521
MARRIAGE	0.070	0.381
HEALTH	-0.310	0.000*
SENSITIVITY	-0.504	0.000*
TIME	-1.408	0.000*

SEA	-1.146	0.000*
GREEN1	-1.822	0.000*
GREEN2	-1.992	0.002*
GREEN1 × *AGE*	0.198	0.345
GREEN2 × *AGE*	-0.276	0.509
GREEN1 × *TIME*	1.055	0.000*
GREEN2 × *TIME*	1.256	0.009*
SEA × *TIME*	-0.211	0.195
SEA × *AGE*	0.439	0.010*
GREEN1 x SEA	0.135	0.464
GREEN2 x SEA	-0.678	0.089

* Significant at 95% confident level

Greenery views and time spent at homes

Results from Table 3.10 suggest that an interaction effect exists between the perception of greenery views and the duration of time spent at home (p<0.05 for *GREEN1* x *TIME* & *GREEN2* x *TIME*). The combined effect of greenery views and the duration of time spent at home was determined by using the coefficient values shown in Table 3.10. For example, the overall effect of longer time spent and a little greenery view is equal to the summation of the individual effect of time spent, individual effect of a little greenery view and the interaction effect between a little greenery views and longer time spent [i.e. 1/exp(-1.408 + (-1.822) + 1.055) (coefficients from Table 3.11) = 8.8 (which is shown in Table 3.11)]. Table 3.11 shows all the computed odds ratios of giving a low annoyance response by a particular group of individuals after taking into account the interaction effects.

Likewise, for an individual having a shorter stay at home, the existence of plenty of greenery views at home is determined to be 7.3 times more likely to feel less annoyed than not having any greenery view (Odds ratios = 7.33). It can be seen from Table 3.11 that the likelihood drops to 6.2 times if only a little greenery view is perceived from his home instead (Odds ratios =6.18). On the contrary, for an individual who has a longer stay at home, the likelihoods of feeling less annoyed are similar irrespective of whether his home has plenty or just a little greenery view (Odds ratio 8.53 vs. 8.80).

Sea views at home and age

Similarly, results from Table 3.10 also suggest that there is an interaction effect between perception of sea views and the age of an individual (p<0.05 for *SEA* x *AGE*). Unlike greenery views, no interaction effect is observed between perception of sea and the duration of time spent at home (p>0.05 for *SEA* x *TIME*). On the contrary, the age of an individual is found to influence the likelihood of the moderation effect of a sea view but not a greenery view on noise annoyance. A younger individual having a sea view at home is 3.2 times more likely to feel less annoyed than a younger individual not having any sea view at home (Odds ratio= 3.15). Likewise, an older individual having sea views at home is only 1.3 times more likely to feel less annoyed than a younger individual whose home does not have any sea view (Odds ratio = 1.28).

Table 3.11
Odds ratios for analyzing annoyance moderation

Personal and dwelling characteristics	Coefficient (β) from Eqn (3.7)	p-value	Odds ratio
Younger Individuals do not have any sea view at homes	0	0.000	1.00
Older Individuals do not have any sea view at homes	0.464	0.000	0.63[a]
Younger Individuals who have sea views at homes	-1.146	0.000	3.15[a]
Older Individuals who have sea views at homes	-0.243	0.000	1.28[a]
Shorter Stay at Home with no	0	0.000	1.00

greenery			
Longer Stay at Home with no greenery	-1.408	0.000	4.09 [b]
Shorter Stay at Home with a little greenery	-1.822	0.000	6.18[b]
Longer Stay at Home with a little greenery	-2.175	0.000	8.80[b]
Shorter Stay at Home with plenty of greenery	-1.992	0.000	7.33[b]
Longer Stay at Home with plenty of greenery	-2.144	0.000	8.53[b]

[a] Odds ratios computed relative to no visibility of sea and younger individuals.
[b] Odds ratios computed relative to no visibility of any greenery and shorter stay at home.

Note:

1. Level 0 of *SEA*, *GREEN1*, *GREEN2* refer to not having any sea view, not having any greenery view, having a little greenery view, having plenty of greenery view respectively and 1 if otherwise
2. Level 0 of *TIME* refers to shorter stay at home and 1 if otherwise
3. Level 0 of *AGE* refers to a younger individual and 1 if otherwise

3.7 Summary

This Chapter has successfully formulated a multivariate quantitative model to estimate the impacts of sea and greenery views, as well as personal characteristics on moderating the noise annoyance responses at homes in the presence of confounding factors. Compared to previous works focusing on the effect of greenery on noise annoyance, our formulated model should convey a more holistic picture as it enables the effects of a multitude of factors on noise annoyance to be investigated simultaneously within a study.

3.7.1 Study I

The results from Study I of this chapter suggest that perception of nearby greenery can generally moderate the noise annoyance rated at home. Different types of greenery setting moderate respondent's noise annoyance to different degrees. Different nature of greenery reduces individual's perceived noise annoyance to different extent. Parks, irrespective of whether they are wetland parks or garden parks, are shown to be able to reduce noise annoyance to a greater extent than grassy hills. On the other hand, the effects of the perceived amount of greenery on noise annoyance reduction at home differ according to the nature of greenery to which residents are exposed. Different amount of greenery perceived by residents living in proximity to wetland parks or garden parks reduces the perceived noise annoyance to different extent. Respondents perceiving a lot of greenery from their apartments generally feel less annoyed than those perceiving only a little. Conversely, different amount of greenery perceived by residents living in proximity to grassy hills is not determined to exert any difference in impacts on noise annoyance reduction. The annoyance rating assigned by respondents who perceive a lot of greenery from their apartments located in proximity to grassy hills are similar to those assigned by respondents who perceive only a little.

3.7.2 Study II

The results from Study II of this chapter suggest that sea views can reduce the likelihood in feeling highly annoyed. The capability of moderating the noise annoyance for sea view can probably be explained by relating to its ability of reducing stress. Small urban parks containing water were rated as more restorative than those without water (Nordh et al, 2009). Respondents who exposed to natural scenes containing water could have positive influences on their psycho-physiological states and emotional states (Ulrich, 1981), or could have their heart rates lowered than those exposed to urban environment (Laumann et al., 2003). However, the nature of setting and proportion of water sources may either have a positive or negative effect on individuals' well-being, and the capability of water sources in producing stress reduction varied (Brown and Taylor, 1992 and Watts et al. 2009). Water sources such as swampy areas are considered to be potentially less preferred and rated significantly less positive than other water sources such as rivers, ponds and lakes (Herzog, 1985).

Compared to greenery views, the moderation effects of noise annoyance due to sea view exposures are reckoned to be weaker, although respondents tended to have stronger preferences for sea views than greenery views (Felsten, 2009; Purcell et al., 2001; White et al., 2010). This probably suggests that the annoyance moderation or restorative effects for different types of nature sceneries are not necessarily related to the degrees of preferences by respondents.

Besides, the moderation effects of sea view and greenery view are also found to vary with some receptor's personal characteristics, such as lifestyle and personal characteristics. This is logical because annoyance is arisen from people's subjective feeling such that the receptors' characteristics should play a more important role. A longer exposure to greenery views can increase the likelihood in assigning low annoyance ratings, but a longer exposure to sea views cannot. On the other hand, the moderation effects provided by sea views are different for different age groups despite the moderation effects provided by greenery views for different age groups are similar. Younger individuals having sea views at homes tend to assign lower annoyance ratings than older individuals.

3.7.3 Limitations

Nevertheless, it is noteworthy pointing out that our study design suffers from a number of shortcomings which may limit the generalization of our findings. Firstly, all our sampled respondents are drawn from a few housing estates in Hong Kong despite a sufficient large number of residents sampled in both of the study.

Secondly, due to resources constraints, the entire data collection period lasted for more than one year as surveys were only conducted during weekends and Sundays. This is based on an assumption that there were no major changes in sceneries and ambient noise levels of the studied sites such that the residents' perceptions would not alter in a long survey period.

Thirdly, sampling bias may arise such that it may impair the representativeness of our findings. In order to minimize the sampling bias, in designing the sampling strategies, we had instructed our researchers and student helpers to randomly selected respondents from all ages, except for minors, The surveys were conducted between 10:00 am and 4:00pm on Saturdays and Sundays so as to minimize the chance of under-representing a majority of the working population who is required to work during weekdays. In fact, it can be seen from the statistical breakdown of the characteristics of the respondents that this sampling bias has been minimized.

Fourthly, our model analysis is limited in the sense that it only includes a limited number of factors, e.g. sound pressure level in dB(A) as the major sound property parameter. However, it does not include other sound properties, view of roadways, length of residence, or personal attitudes towards sound which may have impacts on annoyance. Further studies and analysis should be conducted to embrace these factors.

Also we assumed that there were no other dominant nearby or indoor noise source which might influence annoyance responses at homes.

Fifthly, we only confined the scope of our study to grassy hill, garden and park, and coastal sea. Consequently, only the noise annoyance moderation effects from these two types of greenery can be quantified by our model. Similarly, our findings that sea view exerts weaker influence on noise annoyance than greenery view can only be valid for the built environment sceneries containing these two types of settings. Unfortunately, we did not attempt to differentiate the types of settings and proportion of water sources despite the type of settings and proportion of waterscapes have been shown to exert influences on their moderation effects. Accordingly, it would be valuable to extend the investigation to other types of water sources, like river and lake, before a more generalized effect of water sources can be studied.

Sixthly, the validity of our findings is confined to the relatively low income and less educated group as a majority of our respondents are drawn from this demography. It is suggested that further studies should be conducted to verify whether our findings can be extended to other demographic groups, e.g. higher income or higher educated group.

Seventhly, CRTN prediction method has been utilized to predict the noise exposure at home for our respondents. Therefore, the quantification models constructed in both our studies only apply if the major noise source of the residential estate is road traffic noise. It is therefore valuable if we can extend out study by investigating whether our models can still produce valid prediction of annoyance responses if another noise source, says human noise, also exists.

Eighthly, sea is reckoned to be less effective than greenery in moderating noise annoyance. However, it has not been ascertained whether this is due to the noise from marine vessels passing through the stretch of the sea in Tsuen Wan. Further investigation should be made to determine whether noise from marine vessels is actually perceived by respondents at homes and how frequent they will encounter the noise.

Finally, it is intended to address the sighting effect of natural views by enquiring respondents using the phrase 'can a greenery view (or sea view) be directly spotted from your home apartment?' Despite the results suggesting that the sighting effect from both greenery view and sea view can help relieve the problem of noise annoyance, the accessibility effect from natural views cannot be revealed from the annoyance models established in this chapter. More precise information should be collected from respondents in order to reveal the accessibility effect from natural views, for example, the frequency of visiting the natural environment and the duration of time spent in the natural environment.

CHAPTER 4

VALUE OF REDUCED NOISE ANNOYANCE

4.1 Valuing benefits from noise reduction

Excessive noise may lead to many detrimental impacts. The impacts include productivity impairment (Smith, 1989), deterioration of human well-beings and quality of life (Öhrström, 1991). Exposing to noise level above 55 dB(A) may cause annoyance and sleep disturbance (Stansfeld et al., 2000). Exposing to noise level above 70 dB(A) may induce serious health impacts like myocardial infarction and hypertension (Babisch et al., 2005; Öhrström et al., 2007).

In order to protect residents from exposing to high noise levels, various types of noise mitigation policies and measures have been proposed and implemented by local governments (Tam, 2000). Nevertheless, there is always a concern on the cost effectiveness and the net benefits brought by the proposed policies and measures. Quite often, cost-benefit analysis has been applied for comparing all the costs and benefits of the proposed measures and policies in the same monetary terms.

4.1.1 Revealed preference approach

Valuation of noise benefits poses challenges as noise is regarded as public goods without an explicit market value. To circumvent this drawback, noise benefits are often evaluated in terms of willingness-to-pay. The willingness-to-pay values can be derived using either revealed preference or stated preference approach. The major characteristic of revealed preference approach is that the non-market prices are valued by observing actual behavior and, in particular, purchases made in actual markets (OECD, 2006).

Hedonic price technique is one of the frequently used methods classified under the revealed preference approach. The underlying premise of hedonic price method is that the price of a good is a function of its attributes, including environmental ones. For instance, house prices are considered as a function of characteristics of its structure and function (e.g. orientation, net floor area), neighborhood characteristics (e.g. amount of time required to nearby public transportation facilities) and environmental variables such as noise levels. By applying the hedonic price method, a price can be estimated for a reduction in noise level based upon the difference in house prices provided that all other factors remained unchanged.

Quite often, the willingness-to-pay values derived are expressed in terms of Noise Sensitivity Depreciation Index (NSDI), which gives the percentage decrease in property value per dB increase in noise levels. Table 4.1 shows the details of recent hedonic pricing studies used for predicting loss in property value due to a rise in road traffic noise level. An NSDI of 0.6, for example, suggests that the value of an apartment depreciate by 0.6% if the noise level is increased by 1 dB. In a majority of studies, the NSDI values are derived using L_{eq} as the noise metric. As the estimation of willingness-to-pay values from the hedonic price method is often based on the examination of the past property transaction records (Theebe, 2004), the derived estimates may only reflect the past but not the current behavior of individuals. Also, it cannot be used for reflecting the true economic value of noise for a property market which has not yet reached equilibrium conditions.

Table 4.1
Recent hedonic pricing studies predicting loss in property value from road traffic noise

Study (Author, Year of Publication)	Study Area	Noise Measure	NSDI
Bateman et al., 2004	Birmingham	L_{eq}	0.21-0.53
Bjørner et al., 2003	Copenhagen	-	0.47
Grue et al.,1997	Oslo, Norway – *Obos*	L_{eq}	0.24
Grue et al.,1997	Oslo, Norway – *Flats*	L_{eq}	0.21
Grue et al.,1997	Oslo, Norway – *Houses*	L_{eq}	0.54
Hidano et al., 1992	Tokyo, Japan	L_{eq}	0.7
Iten and Maggi, 1990	Zurich, Switzerland	-	0.9
Lake et al., 1998	Glasgow	L_{10} *(18 hr)*	1.07
Lake et al., 2000	Glasgow	-	0.20
K.S. Kim et al., 2007	Seoul, Korea	-	1.3
Renew, 1996a	Brisbane, Australia	L_{eq}	1.0
Rich and Nielsen, 2004	Copenhagen: houses	L_{eq} *(24 hr)*	0.54
Rich and Nielsen, 2004	Copenhagen apartment	L_{eq} *(24 hr)*	0.47
Soguel, 1991	Neuchatel, Switzerland	L_{eq}	0.91
Vainio, 1995	Helsinki, Finland	L_{eq}	0.36
Wilhelmsson, 2000	Stockholm	-	0.60

4.1.2 Stated preference approach

On the other hand, a direct survey method is often used in stated preference approach to estimate individual or household preferences and more specifically the willingness-to-pay values for changes in provision of non-market goods (OECD, 2006). Stated preference approach often utilizes questionnaire survey either to directly ask respondents for their willingness-to-pay, or offer them several attributes to choose and estimate their willingness-to-pay based on the choices they make. Contingent valuation technique, which is one of the frequently applied methods classified under the stated preference approach, can reflect the current monetary values placed by respondents even though they are based on some hypothetical situations. Contingent valuation has been applied to elicit willingness-to-pay directly from the French respondents for elimination of noise annoyance (Lambert et al., 2001).

On the other hand, Choice Experiments including Discrete Choice Modelling offer respondents several attributes to choose and estimate their willingness-to-pay based on the choices they make. The willingness-to-pay estimates were derived by asking a sampled population in the UK to state their willingness-to-pay values for achieving a 50% reduction in noise level in a choice experiment (Wardman & Bristow, 2004). However, the estimates derived from these studies are of limited application as they failed to relate the willingness-to-pay estimates to an objective noise level. Sometimes, Navrud's assumptions, which are shown in Table 4.2, were proposed to be applied for relating the willingness-to-pay estimates to an objective dB level (Navrud, 2002; Navrud, 2004). Unfortunately, they may lead to considerable errors as the annoyance-dB relationships may vary significantly among nations, and the annoyance-response relationship may be different from what Navrud assumed.

Table 4.2
Navrud's assumptions for relating the willingness-to-pay estimates to a dB level

Scenarios presented in noise surveys	Equivalent dB level
50% reduction in noise level	8 dB
100% elimination of noise annoyance	10 dB
Avoiding a 100% increase in noise levels	10 – 15 dB

Numerous attempts have been initiated to link the stated-preference approach with the traditional socio-acoustic surveys for deriving the willingness-to-pay values per dB reduction. Galilea et al. (2005) attempted to estimate the willingness-to-pay values per dB reduction by correlating the decibel levels measured at the respondents' apartments with the 10-point annoyance ratings (1-10 graded; '1' stands for 'Not at all' and '10' stands for 'Extremely') embraced in their discrete choice experiments. However, their values might not be widely applicable as they were derived from a loosely-fit linear dB-annoyance relationship which could only be applied for a narrow range of noise levels. Arsenio et al. (2006) also estimated the willingness-to-pay values from a sampled population in Portugal using choice experiments. However, their application was restricted to a narrow range of 6 dB(A).

Martin et al. (2006) applied contingent valuation to estimate willingness-to-pay values from the sampled Spanish respondents for rendering their apartments free from noise annoyance. The results were subsequently linked with the linear dB-annoyance relationship for deriving willingness-to-pay estimates per dB reduction. Bjørner (2004) also applied contingent valuation for eliciting willingness-to-pay values from the sampled Danish respondents for eliminating noise annoyance. He pointed out that the probability of assigning a particular annoyance rating varied with the background dB level. However, he failed to establish a quantitative dB-annoyance relationship for deriving willingness-to-pay estimates per dB reduction.

All in all, a majority of the related studies have some shortcomings as they did not take into account: (i) the probability of assigning a particular annoyance rating may vary with the background noise level, or (ii) the annoyance-dB relationship may vary with the particular range of annoyance ratings. Accordingly, this chapter aims to develop a protocol for estimating the willingness-to-pay values for reducing the noise annoyance by using Hong Kong population as an example. The willingness-to-pay values were also derived in terms of dB(A) as they are frequently used for estimating the benefit gains obtained from noise reduction in cost-benefit analysis. This chapter also aims at determining how the annoyance ratings assigned for the background noise levels and personal characteristics will influence the willingness-to-pay values.

4.2 Model for eliciting willingness-to-pay values

Stated preference approach was applied for estimating the current monetary values that would be placed by a respondent. Choice-based conjoint analysis, which is expected to provide more reliable estimates, was applied in conjunction with the socio-acoustic surveys for estimating the willingness-to-pay per dB reduction. Choice-based conjoint analysis was applied for eliciting the willingness-to-pay values for lowering noise annoyance ratings in their apartments. In the meantime, socio-acoustic surveys were used for establishing a relationship between annoyance ratings and the noise level expressed in dB.

4.2.1 Discrete Choice Modeling

Discrete choice modeling, which is a typical choice-based conjoint analysis (Verma and Pullman, 1998), is very effective for analyzing choices in complex decision making situations (Ryan, 1999). It has been widely used for eliciting individual's preferences in spatial consumer choice modeling as well as tourism and recreation research (Louviere, 1984; Verma and Thompson, 1996).

Discrete choice modeling uses questionnaire survey as an instrument for eliciting preferences from respondents. During the survey process, respondents are asked to choose the one they most prefer from a set of profiles. Each profile, composing of a set of attributes with defined levels, is evaluated as a whole by the respondents during the survey. Given that a majority of the preferred profiles are usually selected after decision maker performs tradeoffs among different attributes, discrete choice modeling can be considered to have the capability of portraying the actual decision making process. By analyzing the choices made by the respondents in different pairs of choice cards, the probability of selecting a particular profile from a set of alternatives can be computed. In the meantime, the trade-off decisions made by the respondents among different attributes can also be revealed.

4.2.1.1 Questionnaire design

Our survey instrument comprised three major sections. The first section contained a series of choice cards specially designed to elicit the respondents' importance level ascribed to attributes of a residential apartment located in a particular neighborhood. The second section contained eighteen questions aiming at collecting personal socioeconomic background details like age, education level, and household income level. Such details were collected with an objective to investigate the effects of personal socio-economic backgrounds on their preferences.

4.2.1.2 Identification of attributes and levels of attributes

Experimental design for discrete choice modeling starts with the identification of a set of significant attributes that affects a respondent's preference for a residential apartment in a particular location. Four attributes were chosen for portraying the characteristics of an apartment that residents probably value most: orientation, amount of time taken to travel to nearby public transport facilities, annoyance rating, and monthly rent/ management fee. Table 4.3 lists the four studied attributes together with the associated attribute levels and experimental design codes. A negative sign is used to indicate that the studied condition of a particular attribute is worse than its average condition, while a positive sign is used to indicate that a condition is better than the average.

Table 4.3
Attributes and their corresponding levels utilized in the survey design

Attribute	Level	Design code
Apartment Orientation	Most preferred	+1
	Least preferred	-1
Amount of Time Required to Nearby Public Transportation Facilities	20% less than the duration of time currently needed	+20
	20% more than the duration of time currently needed	-20
Noise Annoyance*	Lower than the current annoyance rating assigned for home by one point	+1
	Same annoyance rating	0
	Higher than the current annoyance rating assigned for	-1

	home by one point	
Monthly Rents / Management Fee	No additional cost	0
	+$25	-25
	+$50	-50
	+$75	-75

*The annoyance rating refers to a five-point verbal scale. Part 2 of the Questionnaire (shown in Appendix B) was to remind respondents of their current residential environment, and of any changes in annoyance rating to which it was referred in the verbal scale shown in Question 3 of that section

Two levels are assigned for describing the apartment orientation and the duration of time taken to nearby public transport facilities; three levels are assigned for noise annoyance ratings; and four levels are assigned for monthly rent/ management fee (see Table 4.3). A full factorial design gave rise to 48 profile combinations (2 x 2 x 3 x 4). However, past experience suggested that respondents could only manage between 9 and 16 pairwise comparisons before degradation of response quality occurred (Pearmain et al., 1991). Therefore, the SPSS orthoplan was applied to incorporate only the main effects and 16 profiles were generated.

4.2.1.3 Block design

A blocking design was applied to further reduce the total number of choice sets required to be completed by an individual respondent. A two-block design was used to divide the 16 profiles into two groups. These two groups formed two separate sets of questionnaires (Block 1 and Block 2), and each consisted of 8 pairwise choices. Table 4.4 shows the factorial design matrix used for generating the choice profiles.

Table 4.4
Fractional factorial design matrix

Choice profiles	Apartment Orientation	Duration of time Required to Travel to Nearby Public Transportation Facilities	Noise Annoyance Rating at Home	Monthly Rents / Management Fee
Block 1				
1	-1.00	-20.00	-1.00	-50.00
4	1.00	-20.00	-1.00	-25.00
5	-1.00	20.00	1.00	-25.00
9	-1.00	-20.00	0.00	0.00
12	1.00	20.00	1.00	0.00
13	1.00	20.00	1.00	-50.00
14	-1.00	20.00	1.00	-75.00
16	1.00	-20.00	0.00	-75.00
Block 2				
2	1.00	-20.00	1.00	0.00
3	1.00	20.00	-1.00	-75.00
6	-1.00	-20.00	1.00	-25.00
7	-1.00	20.00	-1.00	0.00
8	1.00	-20.00	1.00	-50.00
10	-1.00	-20.00	1.00	-75.00
11	1.00	20.00	0.00	-25.00
15	-1.00	20.00	0.00	-50.00

Table 4.5 shows a typical choice set for the questionnaire survey. The survey was conducted via face-to-face so as to minimize the chance of misinterpreting the interview. For each pair of choice cards, respondents were required to choose the one they preferred from the two profiles describing the environmental quality of a residential apartment. Alternatively, they could also choose the ‘neither’ option if they were not satisfied with either profile.

Table 4.5
Example of a choice set

Choice Set 1			
	Scenario 1	**Scenario 2**	
Orientation	Most preferred	Least preferred	
Amount of Time required to travel to the nearby public transportation facilities	+ 20%	+ 20%	
Annoyance Rating	One Point Higher	Unchanged	
Monthly rent/management fee	+$25	+$75	Neither
Preferred Scenario:	( )	( )	( )

4.2.2 Data collection

In identifying suitable survey locations in Hong Kong, two criteria are needed to be fulfilled. Firstly, road traffic should be the major noise source within the estate as Calculation of Road Traffic Noise (CRTN) method (Department of Transport, 1988) would be applied to predict the noise levels at respondents' homes. Secondly, greenery should be located in close vicinity of the examined estates and can be perceived by some but not all of their residents as it is the intent of the surveys to evaluate the value of greenery in reducing noise annoyance. As a result, two estates in Tin Shui Wai and one estate in Tsuen Wan were selected as our survey locations.

Passers-by in the interview locations were randomly approached, and would be invited for an interview if they had indicated that they were inhabitants of the nearby housing estates. Before conducting the survey, each respondent was given ten seconds to listen to the background noise. The questionnaire format utilized in the survey is shown in Appendix B. In the first section of the questionnaire, both five-point verbal scale and eleven-point numerical annoyance scale were used to elicit a respondent's annoyance response to road traffic noises at home over the past twelve months. The choice sets devised for the discrete choice model were included in the second section to portray the characteristics of an apartment that a respondent would value most. The third section of the questionnaire contained a series of questions aiming at collecting respondent's personal details, like age, education level, self-rated noise sensitivity, health status and household income. In addition, the respondents were requested to provide information on the orientation of their homes and the floor levels on which their homes resided. With this information, the Calculation of Road Traffic Noise (CRTN) method (Department of Transport, 1988) was applied to predict the noise levels at the facades of the respondents' homes.

4.2.3 Data analysis and procedures

Discrete choice modeling is rooted from the discrete choice theory (McFadden, 1974; Ben-Akiva & Lerman, 1985), in which choices can be modeled as a function of the attributes of the alternative profiles relevant to a given choice problem. It is assumed that the relative importance is reflected by the part-worth utilities associated with individual attributes, and the choice selected by respondents will normally have the highest overall utility. Given that it is impossible to measure all characteristics of a choice objectively, the overall utility *(U_i)* of choice *i* is considered to have both a deterministic component *(V_i)* and a stochastic component *(ε_i)*.

$$U_i = V_i + \varepsilon_i \tag{4.1}$$

The deterministic component *(V_i)* represents a vector of attributes of the choice that can be measured. In particular, V_i expresses the relative importance of choice attributes as shown in the Model (4.2) below. *Orient* represents major home orientation, *Time* represents the duration of time required for traveling from a respondent's home to nearby public transportation facilities, *Annoyance* represents the noise annoyance rating assigned by the respondent for his home and *Fee* represents the monthly rents or management fee that the respondents were needed to pay.

$$U_i = \beta_{ORIENT} ORIENT + \beta_{TIME} TIME + \beta_{ANNOYANCE} ANNOYANCE + \beta_{FEE} FEE + \varepsilon_i \tag{4.2}$$

where *βs* are coefficients for the i^{th} attribute and ε_i is the error function of the utilities.

The stochastic or random component relates to aspects that prevent choice from being a wholly deterministic process, as implied by the systematic component alone. It includes idiosyncratic, transitory, and a myriad of small influences on choice whose combined effects appear random over time, and other random effects that could result in a respondent's choice varying under identical circumstances.

Although it is assumed that this type of choice behavior is deterministic on the individual level, the probability of choosing alternative *i* can be modeled as an aggregate stochastic process, which can be described as:

$$\text{Prob } \{i \text{ chosen}\} = \text{Prob } \{V_i + \varepsilon_i > V_j + \varepsilon_j ; \forall i, j \in C\} \tag{4.3}$$

where *C* is the set of all possible alternatives. If one assumes that the stochastic elements of the utilities follow a Gumbel distribution, i.e. the errors are independently and identically distributed, the conditional logit model can be used and specified as:

$$\text{Prob } \{i \text{ chosen}\} = e^{Vi} / \sum e^{Vj} \tag{4.4}$$

where the probability of choosing alternative *i* equals the exponent of all the measurable elements of alternative *i* over the sum of the exponent of all measurable elements of all alternatives *j.* The standard conditional logit model limits the systematic component V_i to linear-in-parameters functions, which are usually estimated with a maximum likelihood procedure (Ben Akiva & Lerman, 1985). In particular, the conditional logit model was estimated with the aid of the econometric software LIMDEP.

As it is difficult for a layman to appreciate a decibel change, the noise scenarios are expressed in terms of annoyance ratings in our choice experiment. As a result, only the willingness-to-pay estimates can be derived in terms of a drop in annoyance ratings. With the aid of traditional socio-acoustic surveys, a relationship between the annoyance ratings assigned by the respondents and the noise levels predicted at respondents' homes can be determined. The established relationship is then used for expressing the willingness-to-pay estimates in terms of a dB reduction.

4.3 Willingness to pay for lowering noise annoyance

Prior to a full-scale survey, a trial run was conducted in June 2007 with an objective to remove any ambiguities on the content of the questionnaire design and the method of delivering the questionnaire survey. A full-scale survey was conducted between July 2007 and March 2010 in Tin Shui Wai and Tseun Wan. In total, 1572 surveys were successfully conducted.

4.3.1 Respondents' socioeconomic characteristics

Table 4.6 summarizes the personal socioeconomic characteristics of the respondents. More than half of the respondents were above 40 years old. About half of had attained high school education standard while 39% had college education. A majority of the household income levels of the respondents were below HK$ 50,000. The background noise levels predicted at respondents' homes lie between 50 and75 dB(A). Figure 4.1 shows the frequencies for different ranges of background noise levels predicted for the surveys.

Table 4.6
Summary of the personal characteristics of the respondents

Description	Number of counts (Proportion)
Gender	
Male	704 (45%)
Female	868 (55%)
Age	

≤29	
30-39	181 (11%)
40-49	538 (34%)
50-59	538 (34%)
≥60	232 (15%)
	83 (6%)
Education	
Elementary	125 (8%)
High School	681 (43%)
College	612 (39%)
Graduate	154 (10%)
Monthly household income (HK$)	
≤29999	508 (32%)
30000-49999	485 (31%)
≥50000	421 (27%)

A summary table for the survey studies is shown in Appendix F. The average response rate is forty percent for individual studies. Although the total sample size varied from study to study, the socioeconomics characteristics did not differ very much for the surveyed respondents. The sampled population did not show much difference in age and gender from the entire Hong Kong population. Despite so, the sampled population had a higher education attainment, which might hinder the extending the results to the entire population.

The original questionnaires designed in English were later translated to Chinese before conducting the survey. Both the English and Chinese versions of are shown in Appendix A, Appendix B, Appendix D and Appendix E respectively. All the surveys were conducted in Cantonese.

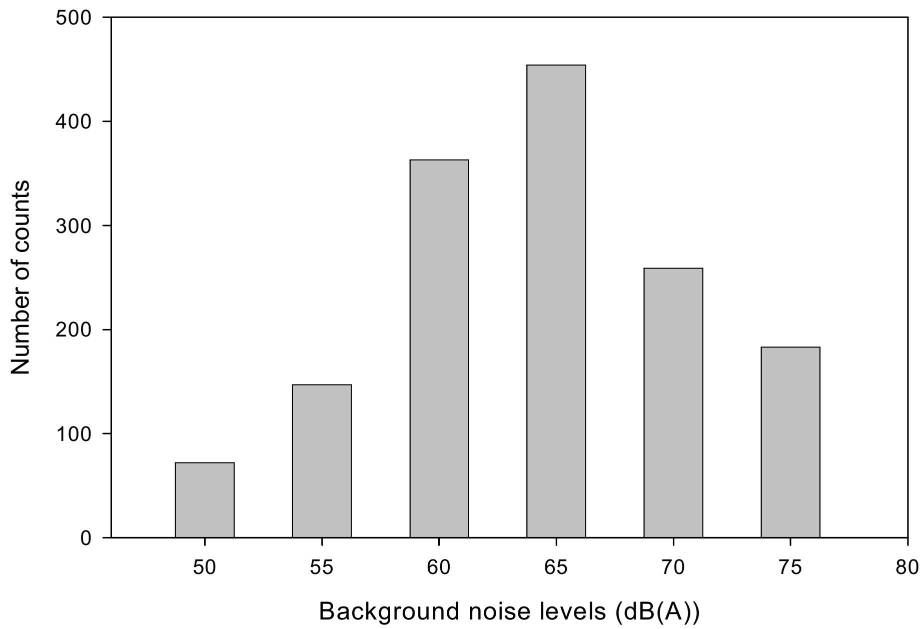

Figure 4.1 Frequencies for different ranges of background noise levels at which the respondents were exposed at their homes

4.3.2 Quality assurance

Prior to the formal data analysis, internal validity and consistency tests were conducted for verifying whether the respondents understood the survey mechanism and the content of choice cards, and for verifying whether they responded to surveys seriously. Internal validity was checked by testing the rationality of the response choices. A control set had already been embedded as one of the choice card pairs in each block of questionnaires. The control sets worked on a presumption that a rational respondent would pick an obviously better profile. If a respondent picked the worse profile instead, all his responses would be discarded with an assumption that he did not respond to the survey seriously. No response data was discarded as all the responses passed this assurance test. As a result, all 1572 survey responses were used for subsequent data analysis.

The results were also tested for internal consistency by examining whether they were consistent with our prior expectations. In particular, the signs in the coefficient estimates for individual attributes were checked to ensure the validity of the results. All the attributes were expected to carry positive signs, as it would be logical to assume that a rational respondent would prefer better environmental qualities in the apartment. For instance, a respondent would always prefer an apartment facing his most favorable direction, as indicated by a positive sign that the respondent's utility would increase with an apartment facing his favorable direction.

4.3.3 The importance of noise annoyance

A conditional logit model was used to fit all the response data. The resulting McFadden's ρ^2 value is 0.18. This suggests that the constructed model fits the response data reasonably well and is valid for portraying the respondents' evaluation of quality of the apartments in a particular location.

Table 4.7
Relative importance of different apartment attributes

Attributes	**Coefficient (β)**	**p-value**
ORIENT	1.098	0.000
TIME	0.020	0.000
ANNOYANCE	1.169	0.000
FEE	0.021	0.000
McFadden's ρ^2	0.18	

All attributes listed in Table 4.7 are significant (with *p*-values ≤ 0.05). This implies that they were all significant factors when the respondents were making decisions on selecting their preferred apartments.

4.3.3.1 Trade-off between different attributes

The tradeoff between different attributes, i.e. the rate at which they are willing to give up one unit of an attribute for an increase in one unit of another attribute, which is also known as the marginal rate of substitution, can be found from the ratio of the coefficients. For example, an individual considered moving from an apartment facing his least preferred orientation to the one facing his most preferred orientation to be the same value as lowering the noise annoyance rating at his apartment by one point. Meanwhile, an apartment facing the most preferred direction was considered to be more important than a 20% reduction in the duration of time required to travel to nearby transportation facilities (1.098/ 0.020), and in turn more important than a reduction in monthly rent/ management fee by $25 (1.098/ 0.021).

4.3.3.2 Willingness to pay for a lower annoyance rating

As money is involved as one of the attributes, the tradeoff ratio between the attribute involving money term and the other attribute will give its willingness-to-pay value. Mathematically, the willingness-to-pay for a lower annoyance rating can be found by the ratio of $\beta_{ANNOYANCE} / \beta_{FEE}$ in Model (4.2). An individual household was found to be willing to pay $55.7[1] monthly for lowering the annoyance rating at their apartment by

[1] The exchange rate for HK$ is currently fixed at US$1 = HK$7.8

one point, or \$52.3 if their apartment was facing the most favorable direction rather than the least favorable direction.

4.3.4 Model for relating the willingness-to-pay values to personal characteristics

In order to determine whether the willingness-to-pay values would vary with the personal characteristics, respondents were segmented according to different household income levels and noise annoyance ratings assigned by respondents, Model (4.2) has been modified to become:

$$\begin{aligned} U_i = {} & \beta_{ORIENT} ORIENT + \beta_{TIME} TIME + \beta_{ANNOYANCExANNOYED(S)} ANNOYANCExANNOYED(S) \\ & + \beta_{ANNOYANCExANNOYED(M)} ANNOYANCExANNOYED(M) \\ & + \beta_{ANNOYANCExANNOYED(H)} ANNOYANCExANNOYED(H) \\ & + \beta_{FEExINCOME(L)} FEExINCOME(L) + \beta_{FEExINCOME(H)} FEExINCOME(H) + \varepsilon_i \end{aligned} \tag{4.5}$$

where '*ANNOYANCE x ANNOYED(S)*' is the noise annoyance rating assigned by the slightly annoyed group, i.e. with an annoyance rating of point 0, 1 or 2 on a 0-10 point scale; '*ANNOYANCE x ANNOYED(M)*' is the noise annoyance rating assigned by the moderately annoyed group, i.e. with an annoyance rating of point 3 or 4; and '*ANNOYANCE x ANNOYED(H)*' is the noise annoyance rating assigned by the highly annoyed respondents, i.e. with an annoyance rating of point 5 or above. '*FEE x INCOME(L)*' is the fee evaluated by the low income group (with household income level below \$20,000); and '*FEE x INCOME(H)*' is the fee evaluated by the high income group (with household income level \$20,000 or above). Wald tests were performed to examine whether there were any significant differences between the coefficient values estimated for each segmented group.

Table 4.8
Effects of income level and annoyance rating assigned for the background noise level on the estimated coefficient values for the major decision attributes

Attribute	Coefficient (β)	p-value
ORIENT	1.099	0.000
TIME	0.020	0.000
ANNOYANCE x ANNOYED(S)	1.105	0.000
ANNOYANCE x ANNOYED(M)	1.181	0.000
ANNOYANCE x ANNOYED(H)	1.204	0.000
FEE x INCOME(L)	0.025	0.000
FEE x INCOME(H)	0.020	0.000
Wald test for β_3 and β_4	0.1146	
Wald test for β_3 and β_5	0.0477*	
Wald test for β_6 and β_7	0.0000**	
McFadden's ρ^2	0.18	

**significant at 0.01 level
*significant at 0.05 level

As shown in Table 4.8, the results confirmed that all respondents valued noise annoyance to be the most important environmental quality for the apartments in a predetermined neighbourhood. More annoyed respondents tended to value noise annoyance higher. The low income respondents who were highly annoyed would be willing to pay $48 (i.e. 1.204/0.025) monthly to lower the annoyance ratings at their homes by one point; and those from the high income group would be willing to pay $60 (i.e. 1.204/0.020). On the other hand, the slightly annoyed respondents from the low income group would be willing to pay $44 (i.e. 1.105/0.025) and those from the high income group would be willing to pay $55 (i.e. 1.105/0.020). However, the results from the Wald test suggest that there is no significant statistical difference between the slightly annoyed respondents and moderately annoyed respondents in valuing the noise annoyance at homes.

In short, it is found that the willingness-to-pay values varied with income levels as well as the annoyance ratings assigned for the background noise levels at homes. As expected, the willingness-to-pay values for the high income group were higher than those for the low income group even if they gave the same annoyance ratings for their homes. Furthermore, the willingness-to-pay value was also found to be increased with the annoyance ratings assigned for the background noise levels at homes.

4.3.5 Annoyance-dB relationships

As mentioned earlier it is important to express the willingness-to-pay values in terms of dB(A) for estimating the benefits for noise reduction in cost-benefit analysis. This is because the effectiveness of the mitigation options is often evaluated in terms of dB. In order to convert the willingness-to-pay values for a lower annoyance rating to the willingness-to-pay values per dB(A) reduction, the assigned annoyance rating needs to be correlated with the background noise level (in dB(A)). This can be achieved by establishing annoyance-dB relationships.

In the following context, the annoyance-dB relationships were established in order to convert the willingness-to-pay values for a lower annoyance rating to the willingness-to-pay values per dB(A) reduction. Results shown in Section 4.3.4 revealed that the annoyance ratings assigned by respondents for their homes significantly affect their willingness-to-pay values. In order to determine the associated willingness-to-pay estimates, the following model was constructed for estimating the average willingness-to-pay value per dB(A) reduction at a particular background noise level, say *x* dB(A):

$$E[\frac{WTP}{dB}]\Big|_x = \sum_{i=1}^{3} \Pr(gp\,i)\Big|_x \times \frac{WTP}{annoyance}\Big|_{gp\,i} \times \frac{annoyance}{dB}\Big|_{gp\,i} \qquad (4.6)$$

where $E[\frac{WTP}{dB}]\Big|_x$ is the average willingness-to-pay value at *x* dB(A); $\Pr(gpi)\Big|_x$ is the probability that a respondent would assign a particular annoyance rating at *x* dB(A); *i=1* corresponds to the slightly annoyed group*; i=2* corresponds to the moderately annoyed group*; i=3* corresponds to the highly annoyed group*;* $\frac{WTP}{annoyance}\Big|_{gpi}$ is the willingness-to-pay values for Group *i*; $\frac{annoyance}{dB}\Big|_{gpi}$ is the annoyance-dB relationship for Group *i*

The probabilities for a respondent to assign a particular annoyance rating can be predicted using Model (4.7). The annoyance-dB relationship for a specific annoyed group was established by correlating the annoyance responses of respondents with the background noise levels at their homes. The annoyance responses were collected by asking the respondents to assign the noise annoyance ratings for their homes during the survey. This information was subsequently used to correlate with the noise levels at homes. The respondents were segmented into three groups according to different annoyance levels. The segmentation is handled exactly in the same way as in the choice experiment discussed previously.

$$Y^*_i = \frac{1}{1+\exp(Z_i - \mu_y)} \qquad (4.7)$$

where μ_y is the threshold value for annoyance rating y estimated for the ordered logit model and the y value ranges from 1 to 10.

Table 4.9 shows the linear annoyance-dB relationships being formulated for each group. It can be seen that the annoyance-dB relationships are different for groups having different annoyances. As shown in Table 4.9, an annoyance rating is equivalent to 5.95 dB(A) for the highly annoyed group, which means that an increase in the background noise level by 5.95 dB(A) at the respondents' homes will raise their annoyance ratings by one point. The dB(A) equivalent for an annoyance rating for the highly annoyed group is found to be higher than that for the moderately annoyed group, and in turn is higher than that for the slightly annoyed group. This suggests that the highly annoyed group is more sensitive to noise than the moderately annoyed group, and the moderately annoyed group in turn is more sensitive to noise than the slightly annoyed group.

Table 4.9
Annoyance-dB relationships for different respondents' groups

Respondents' group	**Annoyance-dB relationship**	**Equivalent dB(A) for an annoyance rating**
Slightly annoyed (i.e. with annoyance rating of 0-2 point)	*Annoyance rating = - 4.1289 + 0.0927 dB* ($r^2 = 0.64$)	10.79
Moderately annoyed (i.e. with annoyance rating of 3-4 point)	*Annoyance rating = - 3.2377 + 0.1100 dB* ($r^2 = 0.66$)	9.09
Highly annoyed (i.e. with annoyance rating >5 point)	*Annoyance rating = - 5.3526 + 0.1681 dB* ($r^2 = 0.74$)	5.95

The analysis of covariance (ANCOVA) has been utilized to check whether the regression lines are significantly different, and the assumption of homogeneity of the regression lines was found to be violated ($F_{(2, 29)}$ = 61.378, p < 0.05).

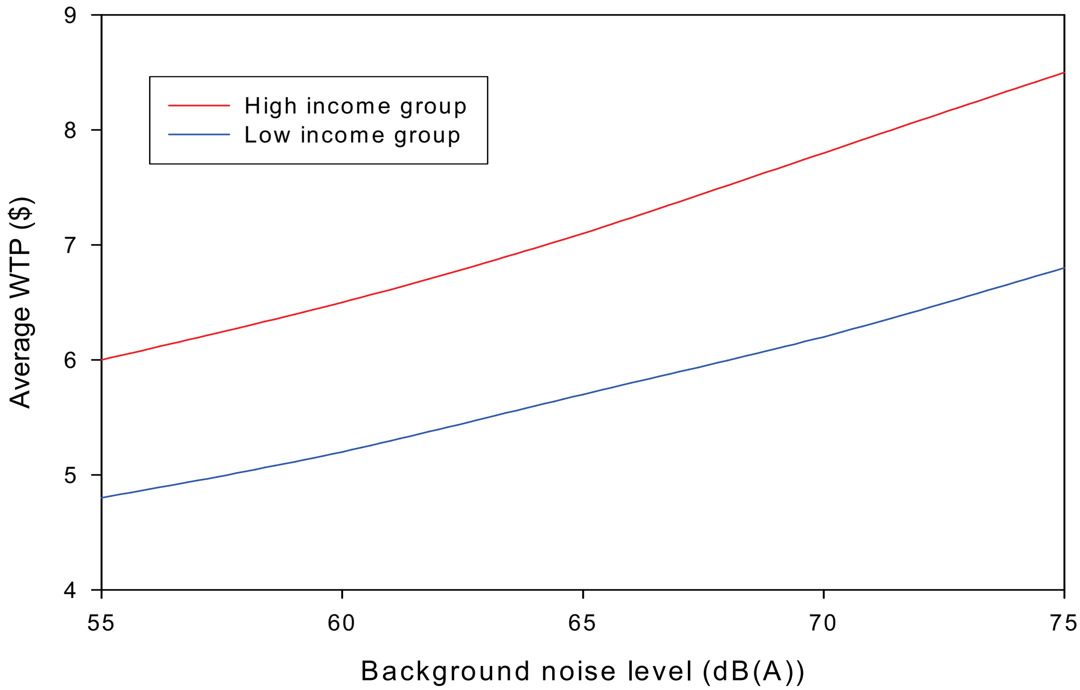

Figure 4.2 WTP values for two income groups if the background noise level is lying between 55 and 75 dB(A)

Figure 4.2 shows the average willingness-to-pay values for two different income groups when the background noise level ranges between 55-75 dB(A). The average monthly willingness-to-pay value per dB reduction per household is found to be increased from $6.0 at 55 dB(A) to $8.5 at 75 dB(A) for the high income group, and increased from $4.8 at 55 dB(A) to $6.8 at 75 dB(A) for the low income group. As expected, the willingness-to-pay value increases non-linearly with the background noise level, and a higher rate of increase is observed at high background noise levels.

4.3.6 Comparison of willingness-to-pay values between Hong Kong and overseas countries

A number of studies have been carried out in different countries to estimate the willingness-to-pay values for noise reduction. In order to compare the willingness-to-pay values between these countries and Hong Kong, the benefit transfer method was applied to transform the willingness-to-pay values from the reported countries to the local Hong Kong context by taking into account some crucial factors that determine the comparability of the countries. In this section, the willingness-to-pay values will be adjusted by taking into account the available information from these studies such as the year of study and Gross Domestic Product per capita according to Model (4.8). Gross Domestic Product (GDP) is defined as the value of all goods and services produced within a country in a given year divided by the average (or mid-year) population for the same year. GDP is included as one of the adjustment factor as it is anticipated that a country with higher GDP will lead to a higher willingness-to-pay value. The willingness-to-pay value is also needed to revert to the year of study by the annualized discount rate.

$$WTP_{adjusted} = WTP_{original} \times DR \times GDP_{HK} / GDP_z \qquad (4.8)$$

where $WTP_{adjusted}$ is the willingness-to-pay value after applying benefit-transfer technique, $WTP_{original}$ is the willingness-to-pay value obtained in other countries, DR is the discount rate per year, GDP_{HK} is the Gross Domestic Product value for Hong Kong and GDP_z is the Gross Domestic Product value in a particular country

Hong Kong is the one of the densest populated cities with the 276 vehicles per kilometer of road (HKSAR government, 2006), which is among the highest in the world. Compared with other countries Hong Kong has a much higher background noise level. However, the derived values for Hong Kong were found to be the lowest when comparing with the resulting willingness-to-pay values from other countries as shown in Table 4.10 after applying benefit-transfer technique. This is partly due to the reason that a majority of the previous studies did not take into account differences in the existing background noise levels in different countries, which may lead to differences in the willingness-to-pay values.

As the traffic volume per meter length of roads in Hong Kong is the highest in the world, the findings should provide valuable insights as this is one of pioneering attempts to place a monetary value on road traffic noise in an Asian city with relatively high road traffic noise levels.

Table 4.10
Comparison of the WTP values per household per month between Hong Kong and the overseas countries

Survey Countries	Study Year	Noise Presentation Unit	Sample Size	dB(A)/ annoyance rating	WTP (in HK$)/ Annoyance rating	WTP/ dB(A) (in HK$)	Sources
Contingent Valuation							
Denmark	2004	dB	1072		86	20	Bjorner & Fosgerau (2006)
Spain	2002	Annoyance	296	12[3]	N/A[4]	N/A[4]	Martín, Tarrero, González and Machimbarrena (2006)
Denmark	2002	dB	1149	16	578 11.25EUR/month	131	Bjorner (2004)
France	2000	Annoyance	331		85[1]	19	Lambert,

			house -holds		73EUR/household/ year		Poisson and Champelovier (2001)
Choice Experiment							
South Korea – Seoul	2001	dB	718 house -holds		223	51	Kang and Hye (2003)
Chile	1999	dB	786	11	78	18	Galilea & Ortuzar (2005)
UK	1996	dB	398		99.97 (loss) 67.76 (gain)	22.72 (loss) 15.40 (gain)	Wardman and Bristow (2004)
Norway	1993	Annoyance	1680		346[1]	79	Saelensminde (1999)

1 Conversion was based on the assumption that 50% noise reduction is equal to 8 dB.
2 Although the study by Kang and Hye in 2003 was also carried out in the Asian region, their study has a major drawback that they only valued the WTP for 1% noise reduction. Besides, they did not include any analysis of the effect of noise level and household income level on the WTP estimates.
3 Value obtained based on a 5-point annoyance scale
4 Only WTP per person per year is available in this study

4.3.7 A refined model for estimating the value of greenery on lowering noise annoyance

In the previous chapter, perception of greenery has been shown to be able to lower noise annoyance ratings assigned for homes. From the benefit perspective, it is of great interest to estimate the monetary value of greenery in reducing noise annoyance. The value of greenery can be estimated by estimating the differences in willingness-to-pay values between respondents who have greenery views from their homes and those who do not have. Model (4.9) shows our formulation in estimating the value of greenery for lowering noise annoyance rating.

$$
\begin{aligned}
&Value\_Greenery|_{x=70} \\
&= \sum_{i=1}^{3} \Pr(gpi)|_{x=70\_with\_greenery} \times E[\frac{WTP}{annoyance}|_{gpi\_with\_greenery}] \\
&- \sum_{i=1}^{3} \Pr(gpi)|_{x=70\_without\_greenery} \times E[\frac{WTP}{annoyance}|_{gpi\_without\_greenery}]
\end{aligned} \qquad (4.9)
$$

where $E[\frac{WTP}{annoyance}|_{gpi\_with\_greenery}]$ is the average willingness-to-pay value for respondents who have greenery view at their homes and have assigned a particular annoyance rating; $E[\frac{WTP}{annoyance}|_{gpi\_without\_greenery}]$ is the average willingness-to-pay value for respondents who do not have any greenery view at their homes and have assigned a particular annoyance rating; $\Pr(gpi)|_{x=70}$ is the probability that respondents will assign a particular annoyance rating at 70 dB(A).

In order to determine whether the willingness-to-pay values vary with the amount of greenery view exposure, Model (4.2) was subsequently modified to become:

$$
\begin{aligned}
U_i &= \beta_{ORIENT} ORIENT + \beta_{TIME} TIME \\
&+ \beta_{ANNOYANCExANNOYED(S)xGREEN(1)} ANNOYANCExANNOYED(S)xGREEN(1) \\
&+ \beta_{ANNOYANCExANNOYED(M)xGREEN(1)} ANNOYANCExANNOYED(M)xGREEN(1) \\
&+ \beta_{ANNOYANCExANNOYED(H)xGREEN(1)} ANNOYANCExANNOYED(H)xGREEN(1) \\
&+ \beta_{ANNOYANCExANNOYED(S)xGREEN(0)} ANNOYANCExANNOYED(S)xGREEN(0) \\
&+ \beta_{ANNOYANCExANNOYED(M)xGREEN(0)} ANNOYANCExANNOYED(M)xGREEN(0) \\
&+ \beta_{ANNOYANCExANNOYED(H)xGREEN(0)} ANNOYANCExANNOYED(H)xGREEN(0) \\
&+ \beta_{FEE} FEE + \varepsilon_i
\end{aligned} \qquad (4.10)
$$

where '*ANNOYANCE x ANNOYED(S)'* is the noise annoyance rating assigned by the slightly annoyed group, i.e. a rating between point 0 - 2 on a 0-10 point scale; '*ANNOYANCE x ANNOYED(M)'* is the noise annoyance rating assigned by the moderately annoyed group, i.e. a rating of point 3 or 4; and '*ANNOYANCE x ANNOYED(H)'* is the noise annoyance rating assigned by the highly annoyed respondents, i.e. a rating of point 5 or above, '*GREEN(1)*' refers to respondents who have greenery views from their homes and '*GREEN(0)*' refers to those who do not have any greenery view.

Table 4.11
Effect of greenery perception on the estimated coefficient values of the major decision attributes

Attribute	Coefficient (β)	p-value	WTP/ annoyance
ORIENT	0.988	0.000	
TIME	0.017	0.000	
ANNOYANCE x ANNOYED(S) X GREEN(1)	1.063	0.000	$55.95
ANNOYANCE x ANNOYED(M) X GREEN(1)	1.132	0.000	$59.58
ANNOYANCE x ANNOYED(H) X GREEN(1)	1.178	0.000	$62.00
ANNOYANCE x ANNOYED(S) X GREEN(0)	1.071	0.000	$56.37
ANNOYANCE x ANNOYED(M) X GREEN(0)	1.207	0.000	$63.53
ANNOYANCE x ANNOYED(H) X GREEN(0)	1.264	0.000	$66.03
FEE	0.019	0.000	
McFadden's ρ^2	0.17		

Table 4.11 shows the effect of a greenery view on the estimated coefficient values for decision attributes. It can be seen that both greenery exposure and the annoyance rating assigned for background noise level influence the willingness-to-pay values. The estimated willingness-to-pay values for different respondents having different amount of greenery exposure are shown in the last column of Table 4.11. Model (4.9) was used to estimate the value of greenery by determining the differences of willingness-to-pay values for respondents with greenery views at homes and those do not have any greenery view. The average monetary value of greenery for a lower annoyance rating is found to be $0.79.

4.4 Summary

This chapter succeeded in taking into account the household income level as well as the assigned annoyance rating in deriving the willingness-to-pay values for lowering the annoyance rating. Our results suggested that the assigned annoyance ratings, which vary with different background noise levels, greatly influence the annoyance responses from respondents. At the same dB(A) level, people initially feel more annoyed are found to be more sensitive to an increase in dB(A) level. Based on these observations, the willingness-to-pay estimates are found to vary non-linearly with the background noise level, even though most of the estimates derived by other studies so far have been assumed to be of constant values. The derivation of willingness-to-pay values which do not take into account the background noise level leads to an erroneous estimation of values for the population under examination.

Of particular value of the findings from this chapter is that an innovative protocol has been developed to estimate the willingness-to-pay values per dB(A) reduction. Instead of simply relying on a linear annoyance-dB(A) relationship for converting the willingness-to-pay values for lowering the annoyance ratings to willingness-to-pay values per dB(A) reduction, the conversion process used the stochastic form of probability functions for describing the chances of respondents in assigning a particular annoyance rating. The average monthly willingness-to-pay value per dB reduction per household is found to be increased nonlinearly from $6.0 at 55 dB(A) to $8.5 at 75 dB(A) for the high income group, and from $4.8 at 55 dB(A) to $6.8 at 75 dB(A) for the low income group.

Besides the knowledge contribution, the work carried out in this chapter is one of pioneering attempts that successfully estimated the willingness-to-pay values for an Asian city. This is important as Asian countries are substantially different in social, institutional and environmental context from those European countries. The willingness-to-pay values are crucial in estimating the benefits in cost-benefit analysis for identifying appropriate noise mitigation measures.

CHAPTER 5

ANNOYANCE RESPONSES IN A MIXED-NOISE SITUATION

5.1 The problem of mixed-noises

A vast number of literatures studying noise annoyance has been focused on responses to a single noise source in particular road traffic, rail or aircraft (Rylander & Bjorkman, 1997; Kurra et al., 1999; Morihara et al., 2004). Some of them studied the annoyance response to road traffic noise and to railway noise independently and then compared the difference in annoyance responses to the two noise sources (Ma & Yano, 2004; Moehler et al., 2000). However, little is known about the relationship between annoyance and noise exposure in the presence of more than one noise source.

The problem of mixed-noises has often been investigated either through field surveys or experimental studies. In field surveys, noise exposure is assessed either through noise prediction model or direct measurement for respective noise sources while the annoyance responses are usually elicited from respondents either through questionnaire surveys or face-to-face interviews. Field surveys facilitate the understanding of the noise annoyance responses aroused from the soundscape as the respondents are experiencing the soundscape on a regular basis. Although the soundscape can be evaluated as a whole in a field study, the contribution of annoyance responses from individual soundscape parameters is complicated to judge. Respondents might not be able to distinguish individual sounds in the soundscape as people could become habituated towards the sounds under a long-term exposure (Namba & Kuwano, 1988).

On the other hand, noise stimuli are prepared in advance for experimental studies and respondents are requested to report their annoyance responses towards the noise stimuli inside controlled experimental chambers. Experimental studies facilitate the assessment of direct relationships between acoustic variables, perception and evaluation after controlling for other non-acoustic parameters which may have influences on noise annoyance responses (Kuwano et al., 2008). However, the validity of the results depends on the similarity between the modeled laboratory environment and the real life situation.

5.1.1 Single models for portraying annoyance responses to mixed-noises

Several different mathematical models, e.g. energy summation model, independent effects model and energy difference model, may be used for correlating the annoyance responses. In the following context, the characteristics of these models will be briefly discussed.

5.1.1.1 Energy summation model

The energy summation model can be used to correlate the total annoyance responses with the resultant noise levels from two noise sources, for example, aircraft noise and road traffic noise, or road traffic noise and railway noise. It is assumed that the annoyance-dB relationships determined from two noise sources are the same such that the annoyance response can be predicted by adding the respective noise levels together. This can be represented by the energy summation model as shown in Model (5.1).

$$A_T = f(L_T) \quad (5.1)$$

where L_T is the resultant noise levels from two sources

5.1.1.2 Energy difference model

Under the energy difference model, the annoyance responses are expressed in terms of the total noise level and the difference in noise level between the two noise sources. The energy difference model takes into account the individual noise levels, i.e. L_1 and L_2 as in Model (5.2), on noise annoyance perception. The major assumption behind is that the annoyance response rating is higher when the difference between the two noise sources becomes smaller even if the resulting sound pressure level L_T remains the same. The formulation of the energy difference model is shown in Model (5.2).

$$A_T = f_1(L_T) - f_2(|L_1 - L_2|) \quad (5.2)$$

where L_T is the resulting sound pressure levels from both noise sources, L_1 and L_2 are the sound pressure levels from the individual noise source.

5.1.1.3 Independent effects model

Within the independent effects model, the annoyance responses are expressed in terms of the two individual noise sources.

$$A_T = f_1(L_1) + f_2(L_2) \quad (5.3)$$

It can be seen from Model (5.3) that two independent functions are assumed for each noise source, L_1 and L_2 and the annoyance-dB relationships determined for individual noise source are assumed to be different in the independent effects model.

5.1.1.4 Characteristics of the three single mixed-noise models

Energy summation model has a simple formulation and therefore is widely used to evaluate the potential noise impact. However, it may cause substantial error in prediction in case the assumption is not valid. Energy difference model is relatively more complicated to apply as more information about the characteristics of the noise sources is needed for formulating the model. Independent effects model also requires more information about the characteristics of the noise sources in formulating the model. However, as a result of differences in formulation between the energy difference model and independent effects model, it needs to check the model fitting information from these models in order to determine which model better accounts for the annoyance responses to the mixed-noises.

The first study that attempted to evaluate the annoyance responses from mixed sources by means of above models can be traced back to 1982. In an attempt to evaluate the effect of a combination of road traffic noise and aircraft noise on annoyance responses, Taylor (1982) identified fifty-six residential sites around Toronto International Airport for examination. Aircraft noise was measured by Integrated Noise Model developed by the United States Federal Aviation Administration, together with a co-ordinate system which helped identify the locations of runways and the sites around the airport for aircraft noise calculations. Road traffic noise was estimated based on field measurement, for which a twenty-four hour record with noise events logging was taken. The total annoyance responses were elicited from respondents through questionnaire surveys.

Taylor evaluated the appropriateness of the above models for portraying the relationships between the mixed-noises and the annoyance responses (Taylor 1982). His results suggested that energy summation model was not too good to explain the variances in annoyance responses due to a low correlation coefficient value of 0.37 being obtained for the model. This may be due to the violation of assumption of the model, i.e. the annoyance-dB relationships for the noise sources are different from what mentioned in Section 5.1.1.1.

On the other hand, energy difference model and independent effects model performed better as they provided acceptable predictions on the annoyance responses based on the information of aircraft noise level and road traffic noise level. Despite so, the correlation coefficients obtained for the energy difference model and independent effects model were only slightly above 0.5. In addition, no standardized or commonly accepted guideline was available for deciding which model to be used (Nilsson, 2001; Öhrström et al., 2007). This led to the development of segmented mixed-noise models for replacing the single mixed-noise models in handling the annoyance responses to a mixed-noise situation.

5.1.2 Segmented mixed-noise models for portraying responses to mixed-noises

In view of the shortcomings, segmented mixed-noise models have been suggested for handling the mixed-noise models under different circumstances. Joncour et al. (2000) intended to determine the total annoyance from residents who were exposing to road traffic noise and railway noise simultaneously. They used a software called MITHRA-FER to predict the emission and propagation of the noises. They considered the scenario as a 'single noise dominant' in case the difference in sound pressure level between the two sources is greater than 5 dB(A). In contrast, the scenario is considered to be 'no dominant' in case the difference is less than 5 dB(A). Öhrström et al. (2007) conducted similar socio-acoustical surveys. They modified the methodology details by incorporating the GIS technology into the noise prediction model. A relationship was established to link the total noise level with the proportion of respondents suffered from noise annoyance. A similar definition for 'no dominant' case and 'single noise dominant' case was used in this study, and the annoyance responses to a 'no dominant' case were found to be higher than to a 'single noise dominant' case. However, it is unclear whether a 5 dB(A) difference used in classifying the 'single noise dominant' case and 'no dominant' case' for combined road and rail traffic noise is also applicable for combined human and road traffic noises.

On the other hand, segmented mixed-noise models can also be formulated based on the results obtained from controlled laboratory experiments in which specific noise sources are often mixed at different levels. Kuhnt et al. (2008) derived an experiment to model the annoyance responses to a combination of road traffic noise and rail noise. Road traffic noise and railway noises were reproduced at 46 dB(A) and 64 dB(A) respectively. Together with a background noise level set at 34 dB(A), noises were subsequently mixed to produce a total of nine scenarios. Participants were invited to participate in the laboratory experiments. They were required to report their annoyance ratings based upon the noise stimuli presented to them in the experiments. The annoyance ratings were regressed against the resultant noise levels to which participants were exposed. Regression models were formulated separately for the case when the sound levels for the two sources are equal (e.g. a combined road traffic noise and railway noise, whose individual noise levels are 46 dB(A)) and for the case when sound levels for the two sources are different (e.g. a combination of road traffic noise at 64 dB(A) and railway noise at 46 dB(A)). The regression analysis showed that the average annoyance rating with equal sound levels for the two sources was higher than that with the different sound levels for the two sources. Although these results were readily observed from the experiments, the effect of the variation in noise composition was not thoroughly investigated.

In short, mixed-noise situation is often handled as a ‘single noise dominant’ case if the difference in sound levels between two sources is greater than 5 dB(A). On the other hand, mixed-noise situation will be handled as a ‘no dominant’ case if the difference is less than 5 dB(A). Segmented mixed-noise models will be constructed to analyze the annoyance responses for different cases. This is based on underlying premises that the dominant noise source solely contributes to the total annoyance responses under a ‘single noise dominant’ case, and both two noise sources contribute significantly to the total annoyance responses under a ‘no dominant’ case. Data for each case will be separately analyzed in order to give better annoyance-responses models (e.g. better goodness of model fit). As segmentation models can provide a better model fit for annoyance, the model development in this chapter generally follows the concept of the segmentation model.

5.2 Experimental design for investigating the annoyance responses to mixed-noises

This chapter aims to design an experiment for examining the annoyance responses to mixed-noises with an ultimate aim of developing models for portraying noise annoyance responses to a mixed human noise and road traffic noise.

5.2.1 Experimental designs for mixed-noises

A controlled experiment was designed to evaluate the annoyance responses to a mixture of road traffic noise and human noise. Mixed-noise stimuli were regenerated from pure road traffic noise and pure human noise recorded in advance. The sample of pure road traffic noise was extracted from a half-an-hour record at the Tuen Mun Highway during rush hours while the sample of pure human noise was extracted from a half-an-hour record in a local restaurant during lunch hours.

The human noise recorded was mainly chatting noise in a restaurant and was used to portray the chatting noise in a residential neighborhood environment. Outdoor recording was not performed as it is rather difficult to record pure human noise at outdoors.

Table 5.1
Noises mixing scenarios

Scenario Identification	Difference in sound pressure levels between road traffic noise and human noise
NS1	-18
NS2	-15
NS3	-12
NS4	-9
NS5	-6
NS6	-3
NS7	0
NS8	+3
NS9	+6
NS10	+9
NS11	+12
NS12	+15
NS13	+18

* A positive sign indicates that road traffic noise is at a higher sound pressure level. A negative sign indicates that human noise is at a higher sound pressure level.

5.2.1.1 Noises mixing

A thirty-second noise sample was extracted from previous sound recordings for both pure road traffic noise and human noise. The noise samples were carefully extracted to ensure as little fluctuation of sound obtained within the whole noise samples as possible. Software called the Power Sound Editor was utilized for noises mixing purpose. The pure road traffic noise was regenerated at various levels and mixed with the pure human noise to produce a total of thirteen noise scripts (i.e. *NS1* to *NS13* as shown in Table 5.1). For example, the human noise was mixed with the road traffic noise whose sound pressure level was lower than that of human noise in *NS1* by 18 dB(A), and the human noise was mixed with the road traffic noise whose sound pressure level was higher than that of human noise in *NS13* by 18 dB(A). All the noise scripts were maintained at a constant noise level using the software.

Figure 5.1 Experimental setup for Head-And-Torso Simulator HATS

All thirteen noise scripts regenerated from the software were analyzed using the Head-And-Torso Simulator (HATS). Figure 5.1 shows the HATS equipment. Two microphones were equipped near the ear region. The sound signal received by the microphones was transmitted to an analyzer for analyzing the acoustical properties of the sound signal. During the experiment, the sound signal from the noise script was input into the simulator through a headphone to reveal the actual noise level that would be perceived by a participant through the headphone. The headphone used in the experiment is made by Sennheiser. The headphone has low impedance (64 Ω) and has an ambient noise attenuation of up to 32 dB. In addition, the headphone is capable of minimizing sound spillage to outside.

The HATS was connected to a personal computer during the preliminary examination of the spectral characteristics of the noise scripts. The volume of the computer was carefully adjusted to maintain sound pressure level at the headphone at 70 dB(A). The volume of the computer was set at 62 which corresponded to the sound pressure level at the headphone of 70 dB(A) as revealed by the HATS.

Figure 5.2 shows the spectral characteristics of *NS1* (shown in dotted line) and *NS13* (shown in solid line) at 70 dB(A) level. It can be seen that *NS1* (i.e. human noise dominant) embraces more low frequency contents, especially at the frequency range below 100 Hz. In contrast, *NS13* (i.e. road traffic noise dominant) embraces more high frequency contents on the average.

Figure 5.2 Spectral characteristics of mixed traffic noise and human noises both at 70 dB(A)

In addition, sharpness and fluctuation strength were also determined for the sampled noise scripts. Sharpness is used to differentiate the sampled noise scripts by examining the proportion of loudness within high critical frequency bands. Sharpness is measured in *acum* and is computed according to the following equation:

$$S = 0.11 \frac{\int_0^{24Bark} N' g(z) z dz}{\int_0^{24Bark} N' dz} \tag{5.4}$$

Fluctuation strength measures the temporary variation in the loudness spectrum due to frequency modulation between 0.25 Hz and 20 Hz. Fluctuation strength is measured in *vacil* and is computed according to the following equation:

$$F = \frac{0.008 \int_0^{24Bark} (\Delta L / dBBark) dz}{(f_{\mathrm{mod}} / 4Hz) + (4Hz / f_{\mathrm{mod}})} \tag{5.5}$$

Table 5.2
Sharpness and fluctuation strength of the noise scripts

Identification Number of scenarios	Sharpness (acum)	Fluctuation strength (vacil)
NS1	1.23	0.81
NS2	1.23	0.79
NS3	1.23	0.76
NS4	1.23	0.73
NS5	1.23	0.71
NS6	1.23	0.68
NS7	1.22	0.64
NS8	1.24	0.6
NS9	1.24	0.58
NS10	1.24	0.56
NS11	1.24	0.52
NS12	1.24	0.3
NS13	1.24	0.3

Table 5.2 shows the acoustical properties of the studied noise scripts. Only little variation in sharpness can be observed among the noise scripts. As sharpness helps differentiate the high frequency components (above 5000 Hz) of the noise scripts, the sharpness values given in Table 5.2 suggest that there are not too much difference in the high frequency components of the studied noise scripts.

On the other hand, the fluctuation strength was found to be relatively higher in case the sound pressure level of human noise was higher than that of road traffic noise. For example, the fluctuation strength of *NS1* (with the sound pressure level of human noise is 18 dB(A) higher than that of road traffic) is the highest among the noise scripts. In contrast, the fluctuation strength of *NS13* (with the sound pressure level of human noise is 18 dB(A) lower than that of road traffic) is the lowest among the noise scripts. A quantification model has been formulated in Section 5.3.2.2 to reveal the impact of fluctuation strength on annoyance responses.

Table 5.3
Custom computer volume output setting

Volume setting	dB(A) output as revealed by HATS
33	55
40	60
50	65

It has been described that all the noise scripts (from *NS1* to *NS13*) were maintained at a constant sound pressure level using the noise mixing software. In addition to the difference in noise composition among the noise scripts, the effect of a variation in the sound pressure level on the difference in annoyance responses is also analyzed in this chapter. All the noise scripts were adjusted to three different sound pressure levels (i.e. 55 dB(A), 60 dB(A) and 65 dB(A)) by means of customized computer volume settings before being presented to participants through headphone. Table 5.3 shows the customized computer volume settings with their respective sound pressure levels. The sound pressure levels were selected in such a way that the variations in annoyance responses at different dB(A) levels could be analyzed in addition to those caused by the variations in noise composition.

5.2.1.2 Experimental set-up and procedure

The experiments were carried out in a study room inside a staff quarter of the Hong Kong Polytechnic University in Hong Kong. The study room was located on the first floor of the building. Figure 5.3 shows the layout of the study room and the experimental location. Inside the room were two bookcases, a desk and a chair with a cushion. The desk was placed near a window such that the outdoor environment could be perceived and daylight was available in the study room. Several plants and magazines were placed on the top of the bookcases.

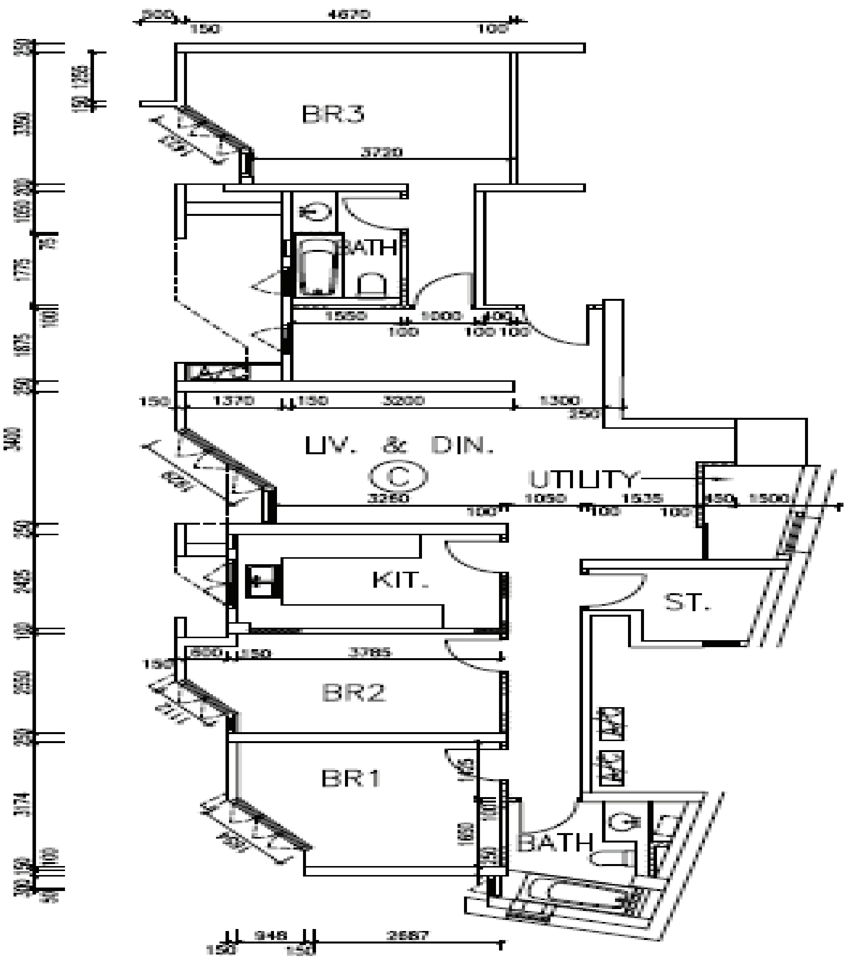

Figure 5.3 Study room inside the university staff Quarter

Several trees of approximately 3 to 4 metres in height could be viewed from the window. Figure 5.4 shows the outdoor view from the study room. Several tall buildings were located in a distance.

Figure 5.4 Outdoor view of the study room

The thirteen noise scenarios, which were stored in a computer placed on the desk, were presented to participants via headphones during the experiments. Participants were requested to relax as if they were staying in their own study rooms while listening to the noise scripts. Magazines were placed near the desk for the participants to read freely during the experiment. Figure 5.5 shows the study room environment.

Figure 5.5 The study room environment

Each of the stimuli was presented to the participants for thirty seconds. After the presentation of each stimulus, next thirty seconds were given to the participants for relaxation and marking down their responses to that stimulus. The responses from each of the stimuli were collected through a 0-10 mono-polar numeric scale (0-10 graded; ‘0’ stands for ‘Not at all’ and ‘10’ stands for ‘Extremely’).

Participants were also required to provide information on their personal characteristics. For instance, a five point scale was used for the participants to report their health status themselves (1-5 graded; ‘1’ stands for ‘Very bad’, and ‘5’ stands for ‘Very good’). Similarly, a five point scale was used for participants to report their noise sensitivity (1-5 graded; ‘1’ stands for, ‘Very sensitive’, and ‘5’ stands for ‘Not sensitive at all’). The whole experiment lasted for about 15 minutes for each participant, including introduction, presentation of stimuli to participants and time breaks for participants to respond to the questionnaire (see the extract of the survey questionnaire shown in Appendix C for more details).

5.3 Experimental results

5.3.1 Participants' personal characteristics

A total of 90 participants were recruited for participating in the experiment between Feb and Mar 2011. All participants were either full-time students or young researchers of the Hong Kong Polytechnic University. They share similar backgrounds such that their confounding effects of personal characteristics on the total annoyance responses can be minimized. Any variances in annoyance responses observed will then be attributed to acoustical factors, i.e. noise level and composition of the noise sources. Table 5.4 summarizes the personal characteristics and their noise exposure levels in the study. Sixty-three percent of the participants were male. Eighty-six percent were aged between 20 and 29 and eighty-six percent were undergraduate students.

Each participant was given a $20 McDonald's coupon as a reward for participating in the experiment. Participants were divided into three groups and each group consists of 30 participants. Each group was exposed to a particular noise level, i.e. 55 dB(A), 60 dB(A) and 65 dB(A).

Table 5.4
Summary statistics of personal characteristic and exposure noise levels for the study

Description	**Number of Counts**
Gender	
Male	57 (63%)
Female	33 (37%)
Age	
≤19	1 (1%)
20-29	86 (96%)
30-39	2 (2%)
40-49	1 (1%)
Education attainment	
Undergraduate	86 (96%)
Master or above	4 (4%)
Occupation	
Undergraduate	85 (94%)
Research student	2 (2%)
Research assistant	3 (4%)
Noise exposure level during experiment	
55 dB(A)	30 (33%)
60 dB(A)	30 (33%)
65 dB(A)	30 (34%)
Total number of participants	90

5.3.2 Modelling of annoyance responses in mixed-noise experiments

The establishment of an ordered logit model for modelling annoyance responses obtained in the experiment follows the concept of segmentation model as mentioned in Section 5.1.2 above. The ordered logit model was utilized to analyze the responses collected in the experiments. The model has the following form:

$$Z_i = \beta_{NOISE} NOISE + \beta_{DIFF} DIFF + \beta_{FLUC} FLUC + \beta_{EQUAL} EQUAL + \beta_{HIGH} HIGH + \beta_{EQUAL \times HIGH} EQUAL \times HIGH + \varepsilon_i \quad (5.6)$$

where Z_i is the ordered logit function, *NOISE* is the background dB(A) level to which the participants were exposed in the experiments, *DIFF* is the difference in dB(A) between the traffic noise and human noise in the noise scripts, *FLUC* is the fluctuation strength of the noise script estimated using Model (5.5), *HIGH* takes on the value of 1 if the noise level is 65 dB(A) and 0 if otherwise, and *EQUAL* takes on the value of '1' if both noise sources contribute significantly to the total annoyance responses ('no dominant' case) and '0' if the dominant noise source contributes to the total annoyance responses solely ('single noise dominant' case), which follows the method of the segmentation model mentioned above. The conditions for 'no dominant' case and 'single noise dominant case' will be determined in the following section.

5.3.2.1 Determining the demarcation range that indicates the noise interval for application of 'single noise dominant' case and 'no dominant' case

A number of previous research studies have studied the annoyance responses in the presence of both road traffic noise and railway noise. The annoyance responses to the mixed-noise situation have always been handled in the following manner. If the noise level of one source is 5 dB(A) higher than that of another noise source, 'single noise dominant' case is assumed such that the dominant noise source solely contributes to the total annoyance response. In contrast, if the difference is less than 5 dB(A), 'no dominant' case is assumed and both noise sources contribute to the total annoyance response.

The total annoyance response under the 'no dominant' case is likely to be higher than that under 'single noise dominant' case even though individuals were exposed to the same noise level. A dominant noise source masks the sound from the other noise source and contributes to the total annoyance response solely, and therefore will make the respondent perceive a lower noise level. This phenomenon is supported by several recent studies (Öhrström et al., 2007; Kuhnt et al., 2008). A simple illustration of the phenomenon is shown in Figure 5.6.

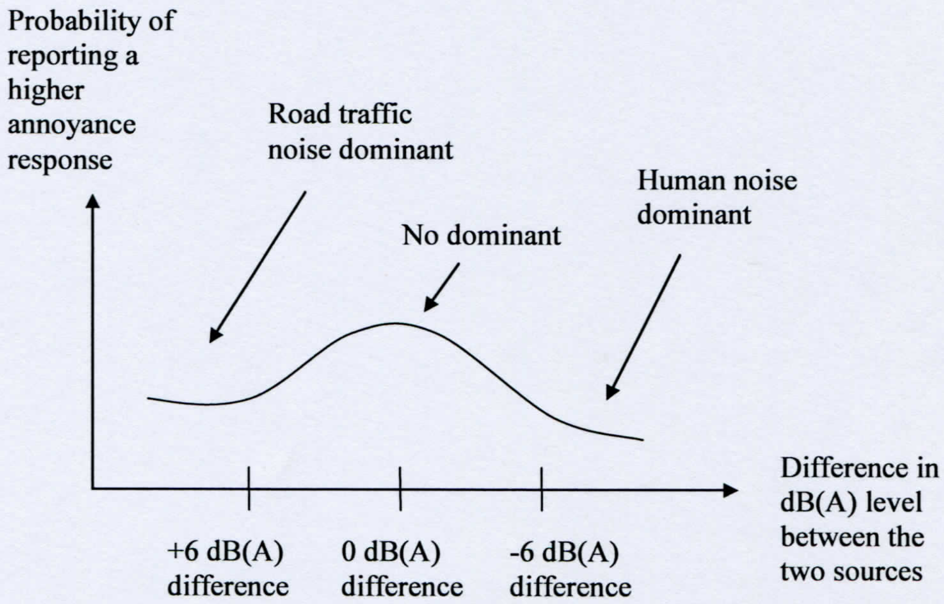

Figure 5.6 Annoyance responses under 'single noise dominant' case and 'no dominant' case

In segmented models, a demarcation range is always used to indicate the noise intervals which are suitable for application of a ‘single noise dominant’ case and a ‘no dominant’ case, and its value is usually expressed in terms of difference in sound levels between two sources. For example, the demarcation range value for road traffic noise and railway noise was proposed to be 5 dB(A) in some recent studies (e.g. Joncour et al., 2000; Cremezi et al., 2001; Lam et al., 2009). The 5 dB(A) demarcation suggests that a ‘no dominant’ source should be considered if the difference in noise level between the two noise sources is within 5 dB(A), or a ‘single noise dominant’ source should be considered if otherwise. However, it is unclear whether this value can be directly applicable for the combined road traffic noise and human noise situation. Accordingly, it is intended to determine the demarcation range value for the mixed road traffic noise and human noise situation. The value is determined based on the above assumption that the annoyance responses to the ‘no dominant’ case is higher than that of ‘single noise dominant’ case. According to Model (5.6), a positive value for $\beta_{EQUALxHIGH}$ indicates the annoyance response under the ‘no dominant’ case is higher than that for ‘single noise dominant’ case even at the same total dB(A) level. Even if the assumption does not hold, Model (5.6) can still be applied to model the annoyance responses to the mixed-noises. Two possible consequences are: (i) a lower annoyance response under the ‘no dominant’ case, as indicated by a negative value for $\beta_{EQUALxHIGH}$ and; (ii) no difference in annoyance response between the ‘no dominant’ case and ‘single noise dominant’ case, for which $\beta_{EQUALxHIGH}$ is always insignificant (p>0.05), i.e. $\beta_{EQUALxHIGH}$ takes on the value of 0 all the time.

Table 5.5
Noise conditions modelled by the ordered logit model

Coding	Respective scenarios
EQUAL (0), HIGH (0)	'Single noise dominant' case at < 65 dB(A)
EQUAL (0), HIGH (1)	'Single noise dominant' case at > 65 dB(A)
EQUAL (1), HIGH (0)	'No dominant' case < 65 dB(A)
EQUAL (1), HIGH (1)	'No dominant' case > 65 dB(A)

The demarcation range value can be determined from Model (5.6). The term *EQUAL* x *HIGH* was used to model the total annoyance responses under 'no dominant' case when the total sound pressure level for the mixed-noises was above 65 dB(A). Supposing the demarcation range value for a mixed road traffic noise and human noise is determined to be 5 dB(A), then the term *EQUAL* x *HIGH* takes on the value of 1 in case the difference between the road traffic noise and human noise is within 5 dB(A) and the total noise level is above 65 dB(A) (see Table 5.5 for more details). A positive value for $\beta_{EQUALxHIGH}$ indicates that the annoyance response under the 'no dominant' case is higher than that under 'single noise dominant' case even at the same total dB(A) level according to Model (5.6).

As the demarcation range value for mixed road traffic and human noise has not been determined at this stage, different values (see Table 5.6 for details) were assumed and checked based against their validity using this criterion: a *p*-value of less than 0.05 for $\beta_{EQUALxHIGH}$ indicates a higher annoyance response under 'no dominant' case according to Model (5.6) and implies that the assumed value is valid.

Table 5.6
Validity of different demarcation range values for combined road traffic noise and human noise

Assigned demarcation range value	*P*-value of EQUAL x HIGH	Valid demarcation range
15 dB(A)	$p>0.05$	No
12 dB(A)	$p>0.05$	No
9 dB(A)	$p>0.05$	No
6 dB(A)	$p<0.05$	Yes
3 dB(A)	$p<0.05$	Yes

Table 5.6 lists the results for different values assumed for demarcation ranges under the combined road traffic noise and human noise scenarios. It can be seen that the term *EQUAL* x *HIGH* is not significant (*p*-value > 0.05) for a demarcation range value of 9 dB(A), 12 dB(A) and 15 dB(A), the annoyance responses from ‘no dominant’ case and ‘single noise dominant’ case are not statistically different and therefore they are not regarded as the demarcation ranges.

In contrast, the term *EQUAL* x *HIGH* is found to be significant (*p*-value < 0.05) for a demarcation range value of 3 dB(A) and 6 dB(A). This suggests that the annoyance response under the ‘no dominant’ case is significantly higher than that under the ‘single noise dominant’ case and therefore they can be regarded as demarcation ranges.

As a demarcation range value of 3 dB(A) suggests that a difference in noise level of less than 3 dB(A) contributes to the ‘no dominant’ case and a demarcation range of 6 dB(A) suggests that a difference in noise level of less than 6 dB(A) contributes to the ‘no dominant’ case, the demarcation range value is determined to be 6 dB(A), i.e. a difference of within 6 dB(A) between the road traffic noise and human noise leads to a 'no dominant' case. And the term *EQUAL* in Model (5.6) takes on the value of 1 if the difference in the noise levels of two sources is within 6 dB(A) and 0 if otherwise.

5.3.2.2 Identifying the potential noise annoyance modifiers in a mixed-noise situation

As shown in Table 5.7, the model gives a McFadden's ρ^2 value of 0.29. This suggests that our response data fits the model very well, and is valid for portraying the noise annoyance responses from the surveyed participants. The good fit of the model is partly due to the fact that both the experimental conditions and the personal characteristics of our participants are controlled to reduce the effects of confounding factors.

Table 5.7
Coefficient estimates for the ordered logit model portraying the annoyance-response relationship in a mixed-noise environment

Model fitting information			
Number of observations			1170
Log likelihood function			-1836.981
McFadden's ρ^2			0.29
Attribute	**Coefficient (β)**	***p*-value**	**Standard error**
Index function for probability			
Constant	-13.173	0.000*	1.740
NOISE	0.336	0.000*	0.028
DIFF	0.066	0.000*	0.016
FLUC	-1.654	0.129	1.090
EQUAL	0.112	0.440	0.145
EQUAL x HIGH	0.486	0.034*	0.230
HIGH	0.578	0.025*	0.258
Threshold parameters for index			
$\mu_{1,1}$	0.000	0.000*	N.A.

$\mu_{2,1}$	2.350	0.000*	N.A.
$\mu_{3,1}$	3.340	0.000*	N.A.
$\mu_{4,1}$	4.160	0.000*	N.A.
$\mu_{5,1}$	5.000	0.000*	N.A.
$\mu_{6,1}$	5.630	0.000*	N.A.
$\mu_{7,1}$	7.000	0.000*	N.A.
$\mu_{8,1}$	8.610	0.000*	N.A.
$\mu_{9,1}$	9.880	0.000*	N.A.
$\mu_{10,1}$	11.150	0.000*	N.A.
$\mu_{1,2}$	0.000	0.000*	N.A.
$\mu_{2,2}$	3.020	0.000*	N.A.
$\mu_{3,2}$	3.920	0.000*	N.A.
$\mu_{4,2}$	4.870	0.000*	N.A.
$\mu_{5,2}$	5.690	0.000*	N.A.
$\mu_{6,2}$	6.400	0.000*	N.A.
$\mu_{7,2}$	7.430	0.000*	N.A.
$\mu_{8,2}$	9.110	0.000*	N.A.
$\mu_{9,2}$	11.130	0.000*	N.A.
$\mu_{10,2}$	12.730	0.000*	N.A.

* Significant at 0.05 levels

The annoyance responses are found to be influenced by the sound pressure level presented to the participants. A positive sign obtained for the dB(A) level indicates that a higher annoyance rating will be assigned by a respondent for a higher sound pressure level. Our results also indicate that the difference in dB(A) level between the traffic noise and human noise also affects the perception of noise annoyance. A positive sign suggests that a higher annoyance rating will be reported if the sound pressure level of road traffic noise level is higher than that of human noise in the mixed-noise script. On the other hand, the fluctuation strength is found to have no significant effect on annoyance responses.

Earlier studies suggested that the annoyance response rating given to mixed-noises with ‘no dominant’ case was higher than that given under ‘single noise dominant’ case even at the same sound pressure level (e.g. Öhrström et al., 2007). However, our results suggest that this only occurs when the noise level is above 65 dB(A). As indicated by the interaction term (*EQUAL* x *HIGH*) in our model, the annoyance rating induced by mixed-noises under 'no dominant' case is higher than that induced by mixed-noises under 'a single noise dominant' case only if the total noise level is above 65 dB(A).

5.3.2.3 Effect of noise sensitivity on noise annoyance responses in a mixed-noise environment

In order to determine the annoyance-responses relationships at different noise compositions (including the human dominant case, and the road traffic dominant case), the probability of assigning a particular annoyance rating is correlated with the difference between the two noise sources using ordered logit function shown in Model (5.6).

In Model (5.6), Z_i takes on different values for different noise composition i, the probability of assigning a particular annoyance rating can be computed using Model (5.7):

$$P(Annoyance = y) = 1 - \frac{1}{1 + \exp(Z_i - \delta_y)} \qquad (5.7)$$

where δ_y is the threshold value for annoyance rating *y* estimated for the ordered logit model and *y* ranges from 1 to 10. Table 5.7 shows the different threshold values. Stratification was applied to analyze the effect of participants' noise sensitivity on perceived noise annoyance. Parameters $\mu_{1,1}$ *to* $\mu_{10,1}$ refer to the thresholds for participants who rated their noise sensitivity as very sensitive, sensitive and average while parameters $\mu_{1,2}$ *to* $\mu_{10,2}$ refer to the thresholds for participants who rated their noise sensitivity as not quite sensitive and not sensitive at all.

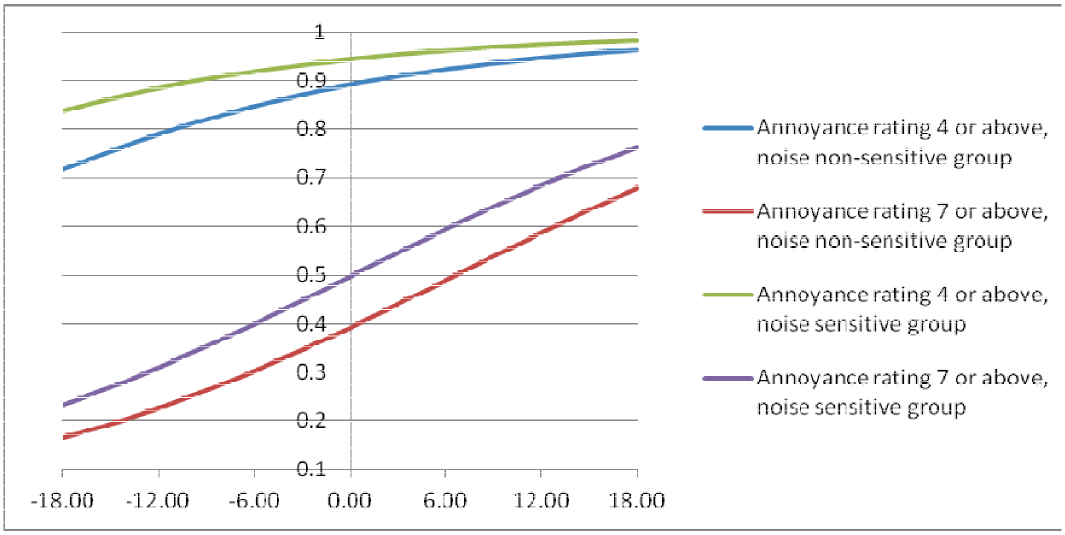

Figure 5.7 Predicted probability for annoyance ratings at 60 dB(A)

Figure 5.7 shows the annoyance responses to mixed-noises for both the noise sensitive group and noise non-sensitive group at 60 dB(A). The noise sensitive group embraces participants who reported their noise sensitivity as ‘very sensitive’, ‘sensitive’ or ‘average’. The noise non-sensitive group embraces those who reported their noise sensitivity as ‘not quite sensitive’ and ‘not sensitive at all’. Obviously, the chances of assigning an annoyance rating of 7 or above are significantly smaller than the chances of assigning an annoyance rating of 4 or above.

In general, it is observed that road traffic noise is more annoying than human noise. Increasing the road traffic noise component in a mixed-noise situation will increase the annoyed population. Noise sensitivity exerts a small but significant effect on annoyance perception. In particular, the chance for noise sensitive group assigning an annoyance rating of 7 or above is 7-11% higher as compared with noise non-sensitive group.

5.4 Summary

Of particular value of this chapter is that an innovative approach has been formulated to determine the demarcation range value for the ‘single noise dominant’ case and ‘no dominant’ case in the presence of both road traffic noise and human noise. A ‘single noise dominant’ case can be assumed if the difference in the sound pressure levels between the road traffic noise and human noise is greater than 6 dB(A), while a ‘no dominant’ case can be assumed if the noise level difference is within 6 dB(A).

While the annoyance models presented in Chapter 3 and Chapter 4 are derived according to the road traffic noise exposure levels of residents based on CRTN method, the results in this chapter suggest that models formulated in these chapters can be applied even if a small proportion of human noise is also present in the residential sites. This is because the human noise has been shown to exert no significant effect on the total annoyance responses in case the noise level of road traffic is higher than that of human noise by more than 6 dB(A), i.e. a ‘road traffic noise dominant’ case.

Compared to previous works, the models presented in this chapter provide valuable insights on the annoyance responses caused by different noise compositions, for example, a mixed road traffic noise and human noise with a 3 dB(A) difference, with 6 dB(A) difference, etc. Öhrström et al. (2007) constructed a model to predict the proportion of population being moderately, very and extremely annoyed by noises at different sound pressure levels. It was reckoned that mixed-noises under ‘no dominant’ case were more annoying than that under ‘single noise dominant’ case at the same sound pressure level. However, this study did not examine how the annoyance responses were affected by different noise compositions. On the other hand, Kuhnt et al. (2008) studied the annoyance responses caused by road traffic noise and railway noise. Road traffic noise and railway noise were reproduced at 46 dB(A) and 64 dB(A) respectively. Together with a background noise level set at 34 dB(A), the noises were subsequently mixed to produce a total of nine scenarios. Even though mixed-noises under ‘no dominant’ case were shown to be more annoying than that under ‘single noise dominant’ case, this study suffered from a major drawback that the number of mixed-noise scenarios under consideration was limited.

Nevertheless, there are several limitations which are considered to be important when interpreting the results from our models. Firstly, our experiment consists of samples for which their personal characteristics are vastly controlled. Most of them are undergraduate students. As there are little variances for their age and education attainment, the effects of age and education attainment on noise annoyance responses cannot be revealed in our model. In addition, the demarcation range of 6 dB(A) for the combination of road traffic noise and human noise could be confined to this socioeconomic background.

Secondly, our models are confined to the application to noise environment comprising road traffic noise and human noise as the major noise sources. Further studies should be conducted to verify whether our findings can be extended to other noise sources such as railway noise and aircraft noise which are also common in Hong Kong. In addition, a living environment with mixed-noises in reality may comprise more than two major noise sources. It is worth investigating whether a significant difference in annoyance responses will be observed in those cases.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1 Conclusions

Noise annoyance has been recognized to be the most important noise impact, and regarded to be well correlated with the background noise level. However, a growing body of evidence suggesting that non-acoustic factors also influence noise annoyance perception to significant degrees.

In this thesis, multivariate stochastic models were successfully formulated for predicting the likelihood of giving a particular noise annoyance response based on a multitude of acoustic, socioeconomic and neighbourhood environmental factors. The findings derived from the formulated model have led to a conclusion that the perception of neighbourhood environmental characteristics like sea and greenery can moderate the noise annoyance at homes. Different types of greenery settings (greenery classified as garden and parks and grassy hill in this study) and different amount of greenery have been shown to be able to moderate noise annoyance to different degrees. On the other hand, sea view is shown to be able to moderate noise annoyance, but its moderation effect is less than that of a greenery view. Also, the moderation effects of a sea view and a greenery view vary with some receptor's personal characteristics. A longer time exposure to greenery views can increase the likelihood in feeling less annoyed, while the younger individuals having sea views at homes tend to feel less annoyed than older individuals having sea views. Besides, acoustical parameters, personal characteristics such as age, education attainment, noise sensitivity and health as well as the duration of time spent at homes also influence individuals' noise annoyance perception.

On the other hand, the monetary worth of reduced noise annoyance was estimated. It is reckoned that the willingness-to-pay (WTP) value for reduced annoyance varies with household income level and the annoyance rating assigned by an individual for the existing dwelling. The WTP per dB reduction per household is found to be increased nonlinearly from HK$6.0 at 55 dB(A) to $8.5 at 75 dB(A) for the high income group, and from $4.8 at 55 dB(A) to $6.8 at 75 dB(A) for the low income group. This should provide benefit information for examining the financial viability of the proposed noise mitigation measures.

Nevertheless, all the foregoing findings were derived based on an underlying premise that road traffic noise was the major noise source. Given that both road traffic noise and human noise may exist at many residential estates in Hong Kong, it is intended to determine whether the models developed in the previous chapters can also be applied to the context of a residential estate where human noise source is also present. To address this objective, a series of controlled laboratory experiments were set up to investigate the noise composition characteristics that warrants the application of a single dominant human noise model, a single dominant road traffic noise model or a combined human noise and road traffic noise model.

Under mixed noises situation, annoyance responses to 'single noise dominant' noise sources and 'no dominant' noise sources are found to be significantly different even under the same dB(A) level. Road traffic noise is found to be the dominant noise source when the sound pressure level of road traffic noise is higher than that of human noise by more than 6 dB(A), and the effect of human noise on noise annoyance is negligible in this case. Accordingly, it is anticipated that the models formulated in the previous chapters can also be applied to residential dwellings where the sound pressure level of road traffic noise is higher than that of human noise by more than 6 dB(A).

Above all, the findings revealed from this thesis pose a significant contribution to the knowledge as both greenery and sea views are shown to be able to reduce noise annoyance. This has a profound impact on city planning and building designs as alternative and complimentary strategies are available for moderating noise annoyance at dwellings and promoting good well-being for modern city-dwellers. Of equal importance is that the protocol developed for estimating the monetary benefits of reduced noise annoyance and value of tree in reducing annoyance can provide essential cost-benefit information for evaluating the financial viability of the proposed noise mitigation measures in a probabilistic manner.

6.2 Recommendations for future work

It is suggested that the moderation effect of nature on noise annoyance perception can be further investigated by extending the scope beyond grassy hill, garden and park, and coastal sea. Future research may extend to other natural features like tree canopy, scrub, woodland, river and lake in order to provide a more holistic assessment on the types of natural features that can help relieve the noise annoyance problem. It is also worth studying whether other natural features such as swamp and pond exert negative effect on noise annoyance perception as they are generally less preferred by individuals.

Further, the noise environment in Hong Kong is quite complicated. It is quite common that residents in many housing estates in Hong Kong may expose to other noise sources, such as railway and construction. Although the models formulated in this thesis are shown to be able to apply to a mixed-noise environment comprising road traffic noise and human noise, more experiments should be performed in order to more accurately predict the annoyance responses under these situations.

On the other hand, the validity of our findings are only confined to individual groups who shares similar personal characteristics as our respondents despite a sufficient number of respondents being sampled for our analysis in the field surveys. Additional surveys should be conducted to investigate whether our findings can be extended to those who have substantially different personal characteristics to reduce the possibility of sampling bias and improve the reliability of the results.

Likewise, although a sufficient number of respondents have been sampled to achieve a good model fit in our analysis for mixed-noise experiments, our results are confined to young individual groups with similar educational background. More samples should be collected to investigate whether a demarcation point value of 6 dB(A) for a mixed traffic noise and human noise is also valid for individuals with different socio-economic backgrounds.

APPENDIX A

Academic Research Questionnaire (sample)

Introduction

Hi, I am a student from Department of Building Services Engineering, the Hong Kong Polytechnic University. Currently, we are conducting an academic research survey about the willingness to pay to reduce the annoyance caused by noise. I hope you could spend 3 to 4 minutes to complete the questionnaire.

Part 1 – Perception about noise

1. **How much does noise from road traffic bother, disturb or annoy you for the moment?** *(Please mark only one box)*

Not at all annoyed *Unbearable*

0 1 2 3 4 5 6 7 8 9 10

How would you rate it if using the following verbal scale?

☐Not at all annoyed ☐Slightly annoyed ☐Moderately annoyed ☐Very annoyed ☐Extremely annoyed

2. **Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic bother, disturb or annoy you?** *(Please mark only one box)*

Not at all annoyed *Unbearable*

0 1 2 3 4 5 6 7 8 9 10

How would you rate it if using the following verbal scale?

☐Not at all annoyed ☐Slightly annoyed ☐Moderately annoyed ☐Very annoyed ☐Extremely annoyed

3. **Do other things about road traffic bother, disturb or annoy you where you live?** (Seen over the last 12 months)

   a) **Air pollution and obnoxious smells:** *(Please mark only one box)*

   ☐Not at all ☐Slightly ☐Moderately ☐Very ☐Extremely

   b) **Dust and dirt:** *(Please mark only one box)*

   ☐Not at all ☐Slightly ☐Moderately ☐Very ☐Extremely

   c) **Vibrations and tremors:** *(Please mark only one box)*

   ☐Not at all ☐Slightly ☐Moderately ☐Very ☐Extremely

Part 2 – Demographic Background

1. Sex: □ Male □ Female
2. Age: □ 19 or below □ 20 - 29 □ 30 - 39 □ 40 - 49 □ 50 - 59 □ 60 or above
3. Educational Level: □ Primary School □ Secondary School □ Degree □ Master or above
4. Types of Residence： □ Public Housing □ Private Housing □ Other
5. Property Ownership: □ Self- Own □ Rented □ Staff Quarters □ Others
6. Personal Monthly Income: □ $4,999 or below □ $5,000-$9,999 □ $10,000-$19,999 □ $20,000-$29,999 □ $30,000-$39,999 □ $40,000-$49,999 □ $50,000-$59,999 □ $60,000-$69,999 □ $70,000-$79,999 □ $80,000-$89,999 □ $90,000-$99,999 □ $100,000 or above
7. Expenditure decision maker: □ Yes □ No
8. Apartment address: ______________________________
9. Apartment orientation: (East/Southeast/South/Southwest/West/Northwest/North/Northeast)
10. Apartment level: □1/F – 5/F □6/F – 10/F □11/F – 15/F □16/F – 20/F □21/F – 25/F □26/F – 30/F □31/F – 35/F □36/F – 40/F □41/F – 45/F □46/F – 50/F □Above 50/F
11. Health status: □Very bad □Bad □Average □Good □Very good
12. Noise sensitivity: □Very sensitive □Sensitive □Average □Not sensitive □Not sensitive at all
13. Perceiveness of greenery: □ Yes (Plenty) □ Yes (Little) □ None

~ The End ~
~ Thank You ~

APPENDIX B

Academic Research Questionnaire (sample)

Introduction

Hi, I am a student from Department of Building Services Engineering, the Hong Kong Polytechnic University. Currently, we are conducting an academic research survey about the willingness to pay to reduce the annoyance caused by noise. I hope you could spend 3 to 4 minutes to complete the questionnaire.

Part 1 – Perception about noise

1. **How much does noise from road traffic bother, disturb or annoy you for the moment?** *(Please mark only one box)*

   Not at all annoyed ... *Unbearable*

   0 1 2 3 4 5 6 7 8 9 10

   How would you rate it if using the following verbal scale?

☐Not at all annoyed ☐Slightly annoyed ☐Moderately annoyed ☐Very annoyed ☐Extremely annoyed

2. **Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic bother, disturb or annoy you?** *(Please mark only one box)*

   Not at all annoyed ... *Unbearable*

   0 1 2 3 4 5 6 7 8 9 10

   How would you rate it if using the following verbal scale?

☐Not at all annoyed ☐Slightly annoyed ☐Moderately annoyed ☐Very annoyed ☐Extremely annoyed

Part 2 – Choice of residential environment (*data collected for chapter 4)

1. **Your most preferred housing orientation is (East/South/West/North) and your least preferred housing orientation is (East/South/West/North).**
2. **Under normal condition, the time taken for you to access to the nearby public transportation is _________** minutes.
3. **According to Part 1, the noise annoyance you encountered at home in the last 12 months or so would be:**

☐Not at all annoyed ☐Slightly annoyed ☐Moderately annoyed ☐Very annoyed ☐Extremely annoyed

4. **The rent / management fee you are paying each month is about $ ________.**

Part 3 - Discrete Choice Questions (*data collected for chapter 4)

(Selection between living condition and noise annoyance)

There are eight pairs of choice cards in the following, each of them represents of two different living environments. Indicate your preference by simply putting a ”x” in the one to represent the one you most prefer.

Combination 1			
	Scenario 1	**Scenario 2**	
Major apartment orientation	Most preferred	Least preferred	
Time required to travel to the nearby public transportation facilities	20% more	20% more	
Annoyance level	Remain unchanged	One level less	
Additional monthly rent / management fee	$25 more	$50 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Combination 2			
	Scenario 3	**Scenario 4**	
Major apartment orientation	Most preferred	Least preferred	
Time required to travel to the nearby public transportation facilities	20% more	20% less	
Annoyance level	One level less	One level less	
Additional monthly rent / management fee	No additional charge	$50 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Combination 3			
	Scenario 5	**Scenario 6**	
Major apartment orientation	Most preferred	Least preferred	
Time required to travel to the nearby public transportation facilities	20% less	20% more	
Annoyance level	One level less	One level more	
Additional monthly rent / management fee	No additional charge	$75 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Combination 4			
	Scenario 7	**Scenario 8**	
Major apartment orientation	Most preferred	Least preferred	
Time required to travel to the nearby public transportation facilities	20% less	20% less	
Annoyance level	One level more	Remain unchanged	
Additional monthly rent / management fee	$25 more	$75 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Combination 5			
	Scenario 9	**Scenario 10**	
Major apartment orientation	Most preferred	Most preferred	
Time required to travel to the nearby public transportation facilities	20% more	20% less	
Annoyance level	Remain unchanged	One level more	
Additional monthly rent / management fee	$25 more	$25 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Combination 6			
	Scenario 11	**Scenario 12**	
Major apartment orientation	Least preferred	Least preferred	
Time required to travel to the nearby public transportation facilities	20% more	20% less	
Annoyance level	One level less	Remain unchanged	
Additional monthly rent / management fee	$50 more	$75 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Combination 7			
	Scenario 13	**Scenario 14**	
Major apartment orientation	Most preferred	Least preferred	
Time required to travel to the nearby public transportation facilities	20% more	20% less	
Annoyance level	Remain unchanged	One level less	
Additional monthly rent / management fee	$25 more	$50 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Combination 8			
	Scenario 15	Scenario 16	
Major apartment orientation	Most preferred	Most preferred	
Time required to travel to the nearby public transportation facilities	20% more	20% less	
Annoyance level	One level less	One level more	
Additional monthly rent / management fee	No additional charge	$25 more	**Neither**
More Preferred Scenario:	( )	( )	( )

Part 4 – Demographic Background

1. Sex: □ Male □ Female
2. Age: □ 19 or below □ 20 - 29 □ 30 - 39 □ 40 - 49 □ 50 - 59 □ 60 or above
3. Marital Status： □ Single □ Married
4. Educational Level: □ Primary School □ Secondary School □ Degree □ Master or above
5. Types of Residence： □ Public Housing □ Private Housing □ Other
6. Property Ownership: □ Self- Own □ Rented □ Staff Quarters □ Others
7. Mainly Home-Staying Period: □ Morning (6am-12nn) □ Afternoon(12nn-6pm) □ At Night(7pm-12am) □ Mid-night(12am-6am) (more than one answer can be chosen)
8. Occupational Status: □ Self-Employed □ Employed □ Student □ House-wife □ Retired □ Other
9. Personal Monthly Income: □ $4,999 or below □ $5,000-$9,999 □ $10,000-$19,999 □ $20,000-$29,999 □ $30,000-$39,999 □ $40,000-$49,999 □ $50,000-$59,999 □ $60,000-$69,999 □ $70,000-$79,999 □ $80,000-$89,999 □ $90,000-$99,999 □ $100,000 or above
10. Household Monthly Income: □ $4,999 or below □ $5,000-$9,999 □ $10,000-$19,999 □ $20,000-$29,999 □ $30,000-$39,999 □ $40,000-$49,999 □ $50,000-$59,999 □ $60,000-$69,999 □ $70,000-$79,999 □ $80,000-$89,999 □ $90,000-$99,999 □ $100,000 or above
11. Expenditure decision maker: □ Yes □ No

12. Apartment address: ____

13. Apartment orientation: (East/Southeast/South/Southwest/West/Northwest/North/Northeast)

14. Apartment level: □1/F – 5/F □6/F – 10/F □11/F – 15/F
□16/F – 20/F □21/F – 25/F □26/F – 30/F
□31/F – 35/F □36/F – 40/F □41/F – 45/F
□46/F – 50/F □Above 50/F

15. Health status: □Very bad □Bad □Average
□Good □Very good

16. Noise sensitivity: □Very sensitive □Sensitive □Average
□Not sensitive □Not sensitive at all

17. Perceiveness of greenery: □ Yes (Plenty) □ Yes (Little) □ None

18. Perceiveness of sea: □ Yes □ No

~ The End ~
~ Thank You ~

APPENDIX C

Academic Research Questionnaire (sample)

Introduction

Hi, we are conducting an academic research about the annoyance reactions from environmental noises. We should be appreciated if you can spend about 15 minutes to complete the questionnaire.

Part 1 – Perception about environmental noises

Thirteen different noise scenarios will be now displayed to you. Each of the scenarios lasts for thirty seconds. A break of thirty seconds will be provided between the noise scenarios. Please indicate how much these noises bother, disturb or annoy you in chronological order in the following table. Please use the following scale when reporting your annoyance level for each scenario.

Not at all annoyed *Unbearable*

0 1 2 3 4 5 6 7 8 9 10

	Annoyance level *(Please **mark only one box** for each noise script)*										
	0	1	2	3	4	5	6	7	8	9	10
Noise script 1											
Noise script 2											
Noise script 3											
Noise script 4											
Noise script 5											
Noise script 6											
Noise script 7											
Noise script 8											
Noise script 9											
Noise script 10											
Noise script 11											
Noise script 12											
Noise script 13											

Part 2 – Demographic Background

1. Sex:	□ Male	□ Female	
2. Age:	□ 19 or below	□ 20 - 29	□ 30 - 39
	□ 40 - 49	□ 50 - 59	□ 60 or above
3. Marital Status：	□ Single	□ Married	
4. Educational Level:	□ Primary School	□ Secondary School	
	□ Degree	□ Master or above	
5. Occupational Status:	□ Undergraduate student	□ Research student	
	□ Research assistant	□ Other	
6. Health status:	□ Very bad	□ Bad	□ Average
	□ Good	□ Very good	
7. Noise sensitivity:	□ Very sensitive	□ Sensitive	□ Average
	□ Not sensitive	□Not sensitive at all	

~ The End ~
~ Thank You ~

APPENDIX D

學術研究問卷（樣本）

導言

您好，我是一名香港理工大學屋宇設備工程學系的學生。目前我們正進行有關市民對道路噪音帶來的煩擾的研究。希望您可以花 3 至 4 分鐘完成問卷。

第 1 部分 - 有關噪音的理解

1. 請問現時的道路噪音有否為您帶來煩擾? 程度如何?

沒有 極度煩擾

0 1 2 3 4 5 6 7 8 9 10

如果只有以下五個程度, 您會如何形容這個程度?

☐沒有 ☐少許煩擾 ☐中度煩擾 ☐非常煩擾 ☐極度煩擾

2. 試回想過去 12 個月在家的時候, 道路噪音有否為您帶來煩擾? 程度如何?

沒有 極度煩擾

0 1 2 3 4 5 6 7 8 9 10

如果只有以下五個程度, 您會如何形容這個程度?

☐沒有 ☐少許煩擾 ☐中度煩擾 ☐非常煩擾 ☐極度煩擾

3. 試回想過去 12 個月在家的時候, 道路噪音有否為您帶來其他煩擾? 程度如何?

a. 空氣污染和厭惡的氣味

☐沒有 ☐少許煩擾 ☐中度煩擾 ☐非常煩擾 ☐極度煩擾

b. 灰塵和污垢

☐沒有 ☐少許煩擾 ☐中度煩擾 ☐非常煩擾 ☐極度煩擾

c. 聲音振動

☐沒有 ☐少許煩擾 ☐中度煩擾 ☐非常煩擾 ☐極度煩擾

第 2 部分 - 個人資料

1. 性別: ☐男性 ☐女性

2. 年齡: ☐ 19 以下 ☐ 20-29 ☐ 30-39
☐ 40-49 ☐ 50-59 ☐ 60 或以上

3. 教育程度: ☐小學 ☐中學
☐學位 ☐碩士或以上

4. 住居類型: ☐公屋 ☐私人住宅 ☐其他

5. 物業業權: ☐私人擁有 ☐租
☐員工宿舍 ☐其他

6. 個人收入 (每月) : ☐$4,999 或以下 ☐$5,000-$9,999
☐ $10,000-$19,999 ☐ $20,000-$29,999
☐$30,000-$39,999 ☐ $40,000-$49,999
☐ $50,000-$59,999 ☐ $60,000-$69,999
☐ $70,000-$79,999 ☐ $80,000-$89,999
☐ $90,000-$99,999 ☐ $100,000 或以上

7. 支出決策者: ☐是 ☐否

8. 住所地址: ____

9. 單位方向: 東 / 東南 / 南 / 西南 / 西 / 西北 / 北 / 東北

10. 單位樓層:
- □1/F – 5/F
- □6/F – 10/F
- □11/F – 15/F
- □16/F – 20/F
- □21/F – 25/F
- □26/F – 30/F
- □31/F – 35/F
- □36/F – 40/F
- □41/F – 45/F
- □46/F – 50/F
- □50/F 或以上

11. 健康狀況: □非常差 □差 □普通 □好 □非常好

12. 噪音敏感度: □非常敏感 □敏感 □普通 □不敏感 □完全不敏感

13. 可在住所看到綠化地方: □看到很多 □看到少許 □看不到

完

APPENDIX E

學術研究問卷（樣本）

導言

您好，我是一名香港理工大學屋宇設備工程學系的學生。目前我們正進行有關市民對減低道路噪音願意付出的價值的研究。希望您可以花 3 至 4 分鐘完成問卷。

第 1 部分 - 有關噪音的理解

1. 請問現時的道路噪音有否為您帶來煩擾？程度如何?

沒有　　　　　　　　　　　　　　　　　　　　　　　　極度煩擾

0　1　2　3　4　5　6　7　8　9　10

如果只有以下五個程度，您會如何形容這個程度?

☐沒有　☐少許煩擾　☐中度煩擾　☐非常煩擾　☐極度煩擾

2. 試回想過去 12 個月在家的時候，道路噪音有否為您帶來煩擾？程度如何?

沒有　　　　　　　　　　　　　　　　　　　　　　　　極度煩擾

0　1　2　3　4　5　6　7　8　9　10

如果只有以下五個程度，您會如何形容這個程度?

☐沒有　☐少許煩擾　☐中度煩擾　☐非常煩擾　☐極度煩擾

第 2 部分 - 居住環境的選擇

1. 您最喜歡的單位方向是（東/南/西/北）。您最不喜歡的單位方向是（東/南/西/北）。
2. 在正常情況下，您前往附近的公共交通設施所需的時間是__________分鐘。
3. 根據第 1 部分，您在家裡遭受的噪音煩擾程度是:

☐沒有　☐少許煩擾　☐中度煩擾　☐非常煩擾　☐極度煩擾

4. 您每月付出的租金/管理費約為$ __________ 。

第 3 部分 - 離散選擇題

（生活狀況和噪音煩擾之間的選擇）
以下有八張選擇卡。每張選擇卡有兩種不同的居住環境。請選擇您最喜歡的那個居住環境,並在那個選擇下打“X” 號。

組合 1			
	居住環境 1	居住環境 2	
單位方向	最喜歡	最不喜歡	
前往附近的公共交通設施所需的時間	快 20%	快 20%	
煩擾程度	維持不變	煩擾少一度	
每月額外租金/管理費	多付 $25	多付 $50	兩者都不喜歡
較喜歡的居住環境:	( )	( )	( )

組合 2			
	居住環境 3	居住環境 4	
單位方向	最喜歡	最不喜歡	
前往附近的公共交通設施所需的時間	快 20%	慢 20%	
煩擾程度	煩擾少一度	煩擾少一度	
每月額外租金/管理費	維持不變	多付 $50	兩者都不喜歡
較喜歡的居住環境:	( )	( )	( )

組合 3			
	居住環境 5	居住環境 6	
單位方向	最喜歡	最不喜歡	
前往附近的公共交通設施所需的時間	慢 20%	快 20%	
煩擾程度	煩擾少一度	煩擾多一度	
每月額外租金/管理費	維持不變	多付 $75	兩者都不喜歡
較喜歡的居住環境:	(　　)	(　　)	(　　)

組合 4			
	居住環境 7	居住環境 8	
單位方向	最喜歡	最不喜歡	
前往附近的公共交通設施所需的時間	慢 20%	慢 20%	
煩擾程度	煩擾多一度	維持不變	
每月額外租金/管理費	多付 $25	多付 $75	兩者都不喜歡
較喜歡的居住環境:	(　　)	(　　)	(　　)

組合 5			
	居住環境 9	居住環境 10	
單位方向	最喜歡	最喜歡	
前往附近的公共交通設施所需的時間	快 20%	慢 20%	
煩擾程度	維持不變	煩擾多一度	
每月額外租金/管理費	多付 $25	多付 $25	兩者都不喜歡
較喜歡的居住環境:	(　　)	(　　)	(　　)

組合 6			
	居住環境 11	居住環境 12	
單位方向	最不喜歡	最不喜歡	
前往附近的公共交通設施所需的時間	快 20%	慢 20%	
煩擾程度	煩擾少一度	維持不變	
每月額外租金/管理費	多付 $50	多付 $75	兩者都不喜歡
較喜歡的居住環境:	(　　)	(　　)	(　　)

組合 7			
	居住環境 13	居住環境 14	
單位方向	最喜歡	最不喜歡	
前往附近的公共交通設施所需的時間	快 20%	慢 20%	
煩擾程度	維持不變	煩擾少一度	
每月額外租金/管理費	多付 $25	多付 $50	兩者都不喜歡
較喜歡的居住環境:	(　　)	(　　)	(　　)

組合 8			
	居住環境 15	居住環境 16	
單位方向	最喜歡	最喜歡	
前往附近的公共交通設施所需的時間	快 20%	慢 20%	
煩擾程度	煩擾少一度	煩擾多一度	
每月額外租金/管理費	維持不變	多付 $25	兩者都不喜歡
較喜歡的居住環境:	(　　)	(　　)	(　　)

第 4 部分 - 個人資料

1. 性別: ☐男性 ☐女性

2. 年齡: ☐ 19 以下 ☐ 20-29 ☐ 30-39
☐ 40-49 ☐ 50-59 ☐ 60 或以上

3. 婚姻狀況: ☐單身 ☐已婚

4. 教育程度: ☐小學 ☐中學
☐學位 ☐碩士或以上

5. 住居類型: ☐公屋 ☐私人住宅 ☐其他

6. 物業業權: ☐私人擁有 ☐租
☐員工宿舍 ☐其他

7. 在家時間: ☐早上 6 點至中午 12 時 ☐中午 12 時至下午 6 時
☐下午 6 時至午夜 12 時 ☐午夜 12 點至早上 6 點

8. 職業: ☐自僱人士 ☐受聘 ☐學生
☐家庭主婦 ☐退休人士 ☐其他

9. 個人收入 (每月) : ☐$4,999 或以下 ☐$5,000-$9,999
☐ $10,000-$19,999 ☐ $20,000-$29,999
☐$30,000-$39,999 ☐ $40,000-$49,999
☐ $50,000-$59,999 ☐ $60,000-$69,999
☐ $70,000-$79,999 ☐ $80,000-$89,999
☐ $90,000-$99,999 ☐ $100,000 或以上

10. 家庭收入 (每月) : ☐$4,999 或以下 ☐$5,000-$9,999
☐ $10,000-$19,999 ☐ $20,000-$29,999
☐$30,000-$39,999 ☐ $40,000-$49,999
☐ $50,000-$59,999 ☐ $60,000-$69,999
☐ $70,000-$79,999 ☐ $80,000-$89,999
☐ $90,000-$99,999 ☐ $100,000 或以上

11. 支出決策者: ☐是 ☐否

12. 住所地址: ____

13. 單位方向: 東 / 東南 / 南 / 西南 / 西 / 西北 / 北 / 東北

14. 單位樓層:
☐1/F – 5/F ☐6/F – 10/F ☐11/F – 15/F
☐16/F – 20/F ☐21/F – 25/F ☐26/F – 30/F
☐31/F – 35/F ☐36/F – 40/F ☐41/F – 45/F
☐46/F – 50/F ☐50/F 或以上

15. 健康狀況:
☐非常差 ☐差 ☐普通
☐好 ☐非常好

16. 噪音敏感度:
☐非常敏感 ☐敏感 ☐普通
☐不敏感 ☐完全不敏感

17. 可在住所看到綠化地方: ☐看到很多 ☐看到少許 ☐看不到

18. 可在住所看到海: ☐看到 ☐看不到

完

APPENDIX F

Summary of the survey studies

Description	HK Population*	Study I (Chapter 3)	Study II (Chapter 3)	WTP Study (Chapter 4)
Gender				
Male	47%	50%	46%	45%
Female	53%	50%	54%	55%
Age				
<39	47%	43%	39%	46%
≥40	53%	57%	61%	54%
Education attainment				
Elementary and High School	77%	52%	51%	51%
College or above	23%	48%	49%	49%
Total sample size	N/A	688	861	1572
Average response rate	N/A	40%	40%	40%
Language used for conducting surveys	N/A	Cantonese	Cantonese	Cantonese

* Data obtained from the Census and Statistics Department of Hong Kong

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