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RESEARCH ARTICLE

Economic value of traffic noise reduction depending on residents' annoyance level

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Abstract
Noise is the most frequently encountered type of environmental pollution in everyday life and has a direct negative effect on humans. Individuals who are constantly exposed to noise tend to have a high incidence of cardiovascular disease and hypertension. Noise sources range from construction sites to political rallies and assemblies, but traffic is one of the most long-lasting and chronic sources of noise. Previously, researchers have conducted valuations of road traffic noise reduction, but they did not consider residents' annoyance levels in response to traffic noise. However, individuals' annoyance levels affect the economic value of noise reduction policies and thus must be considered to obtain an accurate estimate. Therefore, this study investigated residents' willingness to pay for traffic noise reduction depending on their annoyance level. We used the contingent valuation method and a survey to analyze how much 1022 respondents in Korea were willing to pay for noise reduction. We found that people who were annoyed and extremely annoyed by noise had a willingness to pay KRW 8422 (US $7.55) and KRW 9848 (US $8.83) annually per household, respectively, to reduce their annoyance level to zero. In addition, we determined the economic benefits of noise reduction policies using the respondents' willingness to pay to reduce noise by 1 dB(A), which totaled KRW 3.28 billion (US $2.91 million) per year. The results of this study provide estimates of the annual benefits of traffic noise reduction considering residents' annoyance level.

Keywords Annoyance level · Contingent valuation method · Economic value · Traffic noise

Introduction

Road traffic transportation has increased in recent years and is a major source of social problems, including air, water, soil, and noise pollution. Traffic is believed to have negative impacts on the bioavailability of Zn, Cu, Ni, Cd, Cr, and Pb in nearby soils, and soil pollutants must be monitored to preserve environmental quality (Różański et al. 2017). Noise pollution also is a pressing issue associated with road traffic. Noise occurs frequently in everyday life and has direct negative impacts on the human body, including hearing loss, unpleasantness, and stress, which result in sleep disturbance and cognitive impairment. In particular, road traffic noise occurs over a prolonged time period and can be chronic, leading to more serious health consequences than other types of noise. Individuals who are exposed to continuous traffic noise are more likely to develop cardiovascular disease than their non-exposed peers (Babisch 2006). Furthermore, the likelihood of a manifestation of cardio-cerebrovascular disease was reported to increase by 0.17–0.66% when noise increased by 1 dB (Oh et al. 2019). Moreover, noise above a certain level has a

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significantly negative effect on the onset of hypertension (Gopinath et al. 2011). These negative impacts on humans are the main reason why we chose to conduct a study on noise.

In 2012, approximately 16.58 and 1.18 million people in EU-member countries were exposed to average daily noise levels greater than 65 dB(A)[1] and 75 dB(A), respectively. This figure is approximately two times greater than the number of people who were exposed to daytime noise above 65 dB(A) in 2007 and is expected to continue to increase as industrialization and urbanization in Europe continue (European Environment Agency 2017). The residents of Korea are exposed to road traffic noise, as are residents of other developed countries, particularly the metropolises of developed countries that joined the Organisation for Economic Co-operation and Development (OECD) in 2010. This is because Seoul, the capital of Korea, has been rapidly industrialized and urbanized since the 1970s. Seoul is the sixth most densely populated city after London, Berlin, Tokyo, Paris, and Rome (Kim and Kim 2009). Because Seoul is characterized by its high population density, road traffic noise is considered to be one of the most serious social problems in Korea. The National Institute of Environmental Research analyzed exposure to levels of road traffic noise in Seoul using three-dimensional noise maps. Fifteen of 25 districts in Seoul were exposed to higher levels of road traffic noise than the average noise level in European cities; the average exposure level was also higher than that in Europe (National Institute of Environmental 2013).

In Korea, almost 85.7% of the complaints received by the National Environmental Conflict Resolution Commission from 1991 to 2010 concerned civil disputes related to noise and vibration (Anti-Corruption and Civil Rights Commission 2011). Noise levels in some areas exceed the federal allowable noise level established by the Ministry of Environment. In December 2017, the number of registered automobiles in Korea was 22.52 million, which is an increase of 3.3% (720,000 units) over the previous year; the number of registered automobiles is expected to reach approximately 25 million in 2020.[2] The damage caused by traffic noise will increase sharply as traffic volume increases and many cities in Korea widen their roads to accommodate the growing number of domestic vehicles.

Researchers have recognized the gravity of the global traffic noise problem; thus, they have studied noise reduction benefits and social costs of traffic noise. The value of noise can be estimated through the hedonic pricing method (HPM), which is based on revealed preferences (Bateman et al. 2004; Rich and Nielsen 2004). One of the problems with this methodology is that the value of noise reduction can be underestimated (Bjørner et al. 2004). Stated preference–based studies have analyzed surveys with the contingent valuation method (CVM) and respondents' willingness to pay (WTP) in response to changes in aircraft, road traffic, or residential noise levels (Chalermpong and Klaiklueng 2012; Cheramakara et al. 2014; Huh and Shin 2018). The CVM is also used in this study to estimate the WTP for the reduction of road traffic noise in Korea. Although studies on this topic have been conducted, there has been a lack of research focusing on the degree of individual annoyance caused by road traffic noise. This study can be clearly differentiated from others in that we investigate how the WTP changes according not only to the number of children and household income, but also to the degree of annoyance at road traffic noise. Furthermore, through scenario analysis, we show the degree of social benefit when the annoyance level at noise becomes zero.

This study consists of the following sections. The "Background" section discusses the current situation, issues, government regulations related to road traffic noise in Korea, and previous studies on the economic valuation of traffic noise and the dose–response relationship between noise and annoyance. The "Methodology" section reviews the analytical model for deriving the benefits of traffic noise reduction. The "Results and discussion" section discusses the process and results of the questionnaire for stated preference data collection and presents the results of the empirical analysis and the economic benefits of traffic noise reduction. Finally, the "Conclusion and remarks" section calculates the economic costs and benefits of noise-reducing policies and describes some limitations of this study.

Background

Current situation and issues related to traffic noise regulation in Korea

The major causes of traffic noise include traffic volume, traffic speed, and vehicle technical characteristics. The National Noise Information System (NNIS),[3] which confirms the status of domestic road traffic noise, has developed a noise database for the national road network. According to the NNIS, the total domestic network consisted of 1766 branches in 357 areas in 44 cities in 2016. A measurement location is classified according to its general area and a roadside area, of which there were a total of 704.[4] Table 1 shows the noise status of roadside areas in 2016, divided by land use type. The

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[1] dB(A) is a unit of A-weighted sound pressure level, expressed as the magnitude of the sound that can be perceived by the human ear by applying a weight filter to the frequency (Stansfeld et al. 2005). There are other weights, such as B, C, D, and Z, according to the features of noise.

[2] Ministry of Land, Infrastructure and Transportation (stat.molit.go.kr/portal/main/portalMain.do)

[3] National Noise Information System (2018) (http://www.noiseinfo.or.kr/eng/about/info.jsp?pageNo=961)

[4] The 704 roadside measurement sites were located about 1 m from roadside buildings and measured at least once every quarter.

Table 1 Roadside area noise status by city

Roadside area		Standard [dB(A)]	Average noise [dB(A)]	Achievement rate	2016 lowest noise city [dB(A)]	2016 highest noise city [dB(A)]
Residential	Day	65	63	73% (32 cities)	Suncheon [50]	Chuncheon [69]
	Night	55	57	45% (20 cities)	Naju [50]	Seoul [66]
Commercial	Day	70	66	95% (41 cities)	Uijeongbu [56]	Incheon [71]
	Night	60	61	51% (22 cities)	Uijeongbu [52]	Gunpo [67]
Industrial	Day	75	67	95% (41 cities)	Gimpo [56]	Incheon [72]
	Night	70	62	100% (31 cities)	Gimpo [51]	Gunpo [69]

Source: Korea Environment Corporation (2016)

environmental standards for daytime noise levels require that residential areas, commercial areas, and industrial areas do not exceed 65 dB(A), 70 dB(A), and 75 dB(A), respectively.[5] The daytime achievement rate[6] of the environmental standard was as high as 73% in residential areas, 95% in commercial areas, and 95% in industrial areas, whereas the nighttime achievement rates were 45% in residential areas, 51% in commercial areas, and 100% in industrial areas. In the capital of Korea, Seoul, a noise level of 66 dB(A) was recorded at night, making Seoul the city with the highest noise level among residential areas. This nighttime noise level in Seoul is slightly quieter than that of telephone ring tones (70 dB(A)). Thus, it seems necessary for the government to explore every avenue to prevent traffic noise.

Domestic road traffic noise laws are administered by the Ministry of Environment and the Ministry of Land, Transport and Maritime Affairs in Korea. The Ministry of Environment regulates traffic noise by placing clauses related to traffic noise management standards, regulations of automobile operation, and post-environmental impact investigations under the Environmental Policy Basic Law, the Environmental Impact Assessment Act, and the Noise and Vibration Control Act. The Ministry of Land (2018), Transport and Maritime Affairs seeks to reduce noise damage in residential areas through provisions related to the establishment of noise prevention measures in the Housing Act. Notwithstanding these provisions, approximately 30% of residential cities exceed the environmental noise standard in the daytime. Therefore, various regulation countermeasures on the source of traffic noise, propagation routes, and traffic control need to be comprehensively evaluated.

Economic valuation of traffic noise

Because traffic noise has negative physical and mental impacts on humans, it is important to measure sound intensity that is over the standard threshold of hearing. Sound intensity is calculated as the dB of a variable x means $10*\log(x)$, which represents the frequency domain. However, in most cases, noise levels are not represented in dB (decibels) but in dB(A), which is the A-weighted sound level. Other systems of adjustment, such as dB(B) or dB(C), may be used to specify peak or impact noise levels. However, because sound intensity is different from the way that humans perceive noise levels, dB(A) is widely used when measuring the effect of noise levels on humans.

There are two ways to approach the valuation of traffic noise in environmental economics: stated preferences (SP) and revealed preferences (RP). SP methods are related to determining compensation for changes in welfare levels. Among them, the CVM is the most common technique used to obtain the WTP or willingness to accept (WTA) compensation according to changes in the level of non-market goods or services. This non-market valuation method has a strong advantage in that it can measure the economic value of non-quantitative factors and assess the potential for the goods. Chalermpong and Klaiklueng (2012) calculated WTA using the CVM to estimate the compensation value for the increase in aircraft noise from airports in Bangkok, Thailand. Surveys were conducted on alternate scenarios consisting of varying levels of flight frequency and the amount of compensation, resulting in a single plane noise event having a WTA between US $0.63 and US $2.29 per month. Moreover, Cheramakara et al. (2014) estimated payments for a mitigation policy for aircraft noise and local air pollutants for residents near the airport. The residents said they would pay US $3.32 and US $1.44 per year to reduce aircraft noise and air pollution by 1%, respectively. Finally, Carlos (2008) estimated WTA for increased aircraft noise due to a Barcelona airport expansion and found that residents near the airport wanted a reward of US $11.16 each month for every 1 dB(A) increase in aircraft noise.

Arsenio et al. (2006) used the stated choice method to estimate the value of road traffic noise. The researchers conducted a survey using a face-to-face computer-aided personal interview with 412 households to obtain the value of road traffic

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[5] National Noise Information System (2018) (www.noiseinfo.or.kr/eng/about/info.jsp?pageNo=961)

[6] The achievement rate is defined as the percentage of cities that do not exceed the noise standard at any roadside area.

noise per decibel. The study concluded that individuals would pay an additional €2.13 per unit change in L_{eq}. Furthermore, the stated choice method based on perceived noise was found to provide more realistic results than objective measures of noise, which is consistent with the reason why we chose to use the concept of annoyance as perceived noise.

Although SP can convert environmental damage into a direct monetary value, RP can extract the environmental value inherent in a product or market activity by estimating the effects of environmental damage on human health or crops. HPM is the most common technique among RP methods. The method is based on the assumption that the market value of private property involves the value of environmental goods. Housing prices are typically used to estimate the impact of noise on the quality of life. Therefore, the amount of WTP or WTA in HPM would be represented by how the housing prices change to prevent the environmental quality from declining. Some studies use SP and RP concurrently to evaluate the value in reducing traffic noise. Bjørner et al. (2004) used CVM and HPM to determine the value of road traffic noise reduction policies in Copenhagen. In the former method, two groups of people, who experienced noise levels of 55 dB(A) and 75 dB(A) in their residential areas, valuated noise-reduction policies at approximately US $15.39 and US $24.60, respectively, per year for every 1-dB(A) increase. In the latter method, in a residential area exposed to noise levels of 55 dB(A), there was a tendency to decrease the housing price by 0.49% for every 1 dB(A) increase.

Bateman et al. (2004) applied HPM to investigate how sensitive people are to traffic noise and found that real estate prices tend to increase from 0.21 to 0.53% for every 1 dB(A) decrease in Birmingham, UK. With the same method, Rich and Nielsen (2004) studied the impact of noise on decreases in property values. The model revealed losses of 0.54% and 0.47% per 1 dB(A) for houses and apartments, respectively. Grue et al. (1997) estimated the impacts of exposure to road traffic noise using housing prices and the Noise Depreciation Index (NDI), which is related to the ratio of the market value of a house without noise to the market value of a house with noise. The results showed that housing prices tended to decrease by 0.24%, 0.48%, and 0.54% per dB(A) for public apartments, private apartments, and houses, respectively. Nelson (2004) conducted a meta-analysis of 20 different studies to analyze the negative relationship between housing prices and exposure to noise from 23 airports in Canada and the USA. The study determined that the NDI was between 0.50 and 0.70% per dB. Furthermore, the noise discount in Canada was greater than the noise discount in the USA because of differences in legal rules and economic circumstances. Moncayo et al. (2017) estimated the amount that individuals were willing to pay to reduce their annoyance from road traffic noise using an artificial neural network ensemble; compared with an existing probit quantitative economic model, the study's method calculated WTP with 85.7% accuracy in the predicted range.

The increased interest in traffic noise in Korea has led to more estimates of the benefits of noise reduction. Using the CVM technique, Lee and Park (2016) calculated the amount people were willing to pay for the benefit of reduced road traffic noise caused by the installation height of a sound barrier. Lim and Son (2001) estimated the noise value inherent in apartment prices in Seoul's metropolitan areas using the HPM. The summary of previous research on road traffic noise is shown in Table 2. However, there remains a lack of research on the individual characteristics of respondents, such as the degree of annoyance from road traffic noise. Therefore, this study investigates how the benefit of noise reduction is affected by the degree of annoyance with noise as well as sociodemographic characteristics, such as the number of children and household income (Table 2).

Dose–response relationships between noise and annoyance

At this point, it is necessary to define annoyance for the purposes of this study. Annoyance is an emotional state connected to feelings of discomfort, anger, depression, and helplessness (European Environment Agency 2010). To be specific, annoyance at noise in this study refers specifically to the emotional reaction felt by the person who experiences the noise; it does not include the physical effects that he or she may experience without recognition. Thus, the survey asked respondents to refer only to feelings about noise in order to minimize the risk of this potential double counting of emotional and physical noise impacts. To date, various studies have been carried out in the field of environmental engineering on the relationship between noise and annoyance. Studies on annoyance start from examining the interaction of a specific noise source with the annoyance of exposed people (Park and Kim 2014). Most of the surveys related to annoyance from noise were conducted using 5-point or 11-point Likert scales proposed by the International Commission on Biological Effects of Noise (ICBEN). The results of the psychological response through the surveys are expressed as %A or %HA, which are the percentage of the residents annoyed or highly annoyed (Miedema and Oudshoorn 2001). According to the European Commission (2002), the percentage of people who felt extremely annoyed (%HA) tends to increase exponentially as noise levels from aircraft, roads, and railways increase.

At railway noise levels of 59 dB(A) and 63 dB(A), 20% and 40% of people felt extremely annoyed, respectively (Ögren et al. 2017). Another study showed that the percentage of people who felt extreme annoyance due to large wind turbine noise was close to 0 at less than 40 dB(A); the rate began to increase slowly with levels exceeding 40 dB(A) (Valtteri and David 2017). In addition, the relationship between noise and annoyance showed that the level of annoyance was close

Table 2 Summary of past studies on road traffic noise

Author	Method	Type of noise	Value*	Location
Grue et al. (1997)	HPM (RP)	Road traffic	0.24% (public apartments)0.48% (private apartments) 0.54% (houses)	–
Bateman et al. (2004)	HPM (RP)	Road traffic	0.21–0.53%	Birmingham
Bjørner et al. (2004)	HPM + CVM (RP + SP)	Road traffic	0.49%	Copenhagen
Nelson (2004)	HPM (RP)	Aircraft	0.50–0.70%	Canada and the USA
Rich and Nielsen (2004)	HPM (RP)	Road traffic	0.54% (houses)0.47% (apartments)	Copenhagen
Arsenio et al. (2006)	CVM (SP)	Road traffic	€2.13	–
Carlos (2008)	CVM (SP)	Aircraft	US $11.16	Barcelona Airport
Chalermpong and Klaiklueng (2012)	CVM (SP)	Aircraft	US $0.63–2.29	Bangkok Airport

*The economic value of a road traffic noise reduction policy was represented by the willingness to pay (US $) and the rate of housing price changes (%) in comparison with not enforcing the policy

SP stated preferences, *RP* revealed preferences

to 0 when noise from the road was 45 dB(A); the level of annoyance increased sharply when the noise exceeded 60 dB(A) (Sabine and Henk 2011).

Furthermore, the European Environment Agency (2010) investigated the critical points of noise levels that affect human health in many ways. For instance, people experience sleep disturbances as the noise level exceeds $42L_{den}$. As the noise level exceeds $50L_{den}$ and $60L_{den}$, the risk of hypertension and ischemic heart disease increases. Moreover, the European Environment Agency (2010) also proposed a relationship between transportation noise and annoyance (%HA) using a dose–response equation. The results show that people feel extreme annoyance as the noise level of transportation exceeds $42L_{den}$. Thus, $42L_{den}$ is referred to as the critical point that affects annoyance. Considering all of these different results and prior research, we defined $42L_{den}$ as the noise level at which people start to feel annoyance. In other words, when the noise level drops below $42L_{den}$ due to a noise reduction policy, people do not feel any annoyance at all. This implication is addressed in the "Economic benefits of traffic noise reduction policies" section of this study.

Methodology

This study evaluated non-market goods (which are not traded in the market) and sought to evaluate the benefits of reducing traffic noise. CVM is a methodology to measure the economic benefits of non-market goods. Although it has several limitations (as discussed in Appendix A), CVM is widely used by policy makers and economists to evaluate the benefits of non-market goods. With the CVM method, we calculated WTP using survey results on the goods to be evaluated.

This study used the utility difference model of Hanemann (1984) to analyze WTP for reducing noise levels. We used the double-bounded dichotomous choice model (DBDC) to estimate WTP. The respondents were asked to select *yes* or *no* for the amount presented in the utility difference model. The response data were modeled to calculate the sample mean of the WTP; then, the parameters were estimated by the maximum likelihood estimation method. According to Hanemann (1984), who derived the Hicksian compensation surplus, the following indirect utility function (u) can be derived from respondents' interest income (m) and characteristic vector (S), assuming that they correctly grasp their utility function based on the utility maximization theory:

$$u(j,m,S) = v(j,m,S) + \varepsilon_j \tag{1}$$

where $j = 0$ is a state in which there is no attempt to reduce road traffic noise, whereas $j = 1$ is an attempt to pay an appropriate amount to reduce road traffic noise. The non-observable stochastic part, ε_j, included in the indirect utility function is independently and identically distributed regardless of the state j; the average of this distribution is assumed to be 0. If the respondent answers *yes* to the question, "Are you willing to pay the amount of payment (A) to reduce road traffic noise?" then the probability that the respondent will answer *yes* to the proposed amount is as follows:

$$\Pr(\text{Yes}) = \Pr(\Delta \text{v} \geq \varepsilon_0 - \varepsilon_1) = F_{\varepsilon_0 - \varepsilon_1}(\Delta \text{v}) \tag{2}$$

where Δv, $\Delta \text{v} = \text{v}(1,\text{m} - \text{A},\text{S}) - \text{v}(0,\text{m},\text{S}) \geq \varepsilon_0 - \varepsilon_1$, is the increment of the indirect utility that all respondents can obtain through the reduction of road traffic noise.

Because the random variable in the willingness to pay is C, unique to the respondent, the respondent is assumed to have C equal to or greater than the bid amount, A. Therefore, $\Pr(\text{Yes}) = \Pr(\text{C} \geq \text{A})$ is the probability that the respondent is willing to pay the amount presented:

$$\Pr(\text{Yes}) = F_{\varepsilon_0 - \varepsilon_1}(\Delta \text{v}) = \Pr(\text{C} \geq \text{A}) = 1 - G_C(A) \tag{3}$$

G_C is the cumulative distribution function of C, that is, the maximum WTP of the individual. In addition, estimating the WTP model implies figuring the parameters of G_C.

In the DBDC model, if respondents answer *yes* to the first bid amount, A, they will be asked about a second bid amount, 2A. If not, they are given the amount, A/2, which is equivalent to half of the first bid amount. The answers to each situation can be defined as follows:

$$\begin{aligned} I_i^{YY} &= 1\ \left(\text{if the respondent's answer is}^{B}\text{yes}^{\wedge}\text{—}^{B}\text{yes}^{\wedge}\right) \\ I_i^{YN} &= 1\ \left(\text{if the respondent's answer is}^{B}\text{yes}^{\wedge}\text{— }^{B}\text{no}^{\wedge}\right) \\ I_i^{NY} &= 1\ \left(\text{if the respondent's answer is}^{B}\text{no}^{\wedge}\text{—}^{B}\text{yes}^{\wedge}\right) \\ I_i^{NN} &= 1\ \left(\text{if the respondent's answer is}^{B}\text{no}^{\wedge}\text{— }^{B}\text{no}^{\wedge}\right) \end{aligned} \quad (4)$$

The log likelihood function of the DBDC model is as follows:

$$\begin{aligned} \text{lnL} = \textstyle\sum_{i=1}^{M} \Big[& I_i^{YY} \cdot lnP^{YY}(\text{A}, 2\text{A}) + I_i^{YN} \cdot lnP^{YN}(\text{A}, 2\text{A}) \\ & + I_i^{NY} \cdot lnP^{NY}(\text{A}, \text{A}/2) + I_i^{NN} \cdot lnP^{NN}(\text{A}, \text{A}/2) \Big] \end{aligned} \quad (5)$$

where the probabilities of the individual responses are P^{YY}, P^{YN}, P^{NY}, and P^{NN}. In each case $P^{YY}(\text{A, 2A}) = 1 - \text{G(2A)}$, $P^{YN}(\text{A, 2A}) = \text{G(2A)} - \text{G(A)}$, $P^{NY}(\text{A, A/2}) = \text{G(A)} - \text{G(A/2)}$, and $P^{NN}(\text{A, A/2}) = \text{G(A/2)}$.

After applying the cumulative distribution function, G_C, to the log-likelihood function, the study can obtain the values of the parameters a and b to be estimated through the maximum likelihood estimation method. Then, the mean WTP for the reduction of road traffic noise from the estimated parameters can be estimated as:

$$\text{WTP} = (1/\text{b}) \cdot \ln(1 + \exp(\text{a})) \quad (6)$$

Results and discussion

Data

The contingent valuation (CV) questionnaire for collecting preference data was administered to 1022 individuals aged 20–65 years in Seoul, Gyeonggi, and six other metropolitan cities in Korea. The survey was conducted in April 2017. For questionnaire reliability, respondents were limited to individuals who had the right to make the actual payment (the head of household or their spouse). Fieldwork was conducted by a professional polling firm (Gallup Korea) as an online survey. To collect a sample group that was representative of the population composition in Korea, respondents were selected based on area and age.

The questionnaire consisted of three major parts. Part A asked how respondents accept noise and related policies generally. This included questions about the intensity and frequency of noise experienced in daily life, interest in environmental noise, level of annoyance due to noise, and satisfaction with the sound insulation level. These questions allowed us to check the impact of these factors on the amount of noise and related payments to the policy. Part A was also used to capture the attention of respondents prior to the full CV questions.

Part B consisted of the full set of CV questions. It included the description and classification of noise, the damage and impact of noise, the description and purpose of the noise reduction policy,[7] and the expected effects of the implementation of the measures. In particular, this study compared the relative value of living noise and traffic noise. CV questionnaires about these two kinds of noise were conducted separately. Living noise includes floor and construction noise, whereas traffic noise includes road traffic, aircraft, and railroad noise. The survey explained that additional costs are needed to implement noise reduction measures, which would be covered by income tax hikes. Income tax is a frequently used payment vehicle in CVM surveys (Kuhfuss et al. 2016; Morrison et al. 2000).

When using CVM, especially the dichotomous choice method, setting the initial bid amounts is vital for accurate WTP derivation (Herriges and Shogren 1996; McLeod and Bergland 1999). To this end, this study conducted a pre-test,[8] and five initial values were set for each noise type. The survey asked if the respondents were willing to pay the initial bid annually over the next five years through their income tax to reduce their annoyance at noise to zero. Table 3 shows five initial bids and the number of respondents who completed the CV questionnaire based on the corresponding amount.

The last part of the CV questionnaire examined respondents' socioeconomic and demographic characteristics, such as gender, education, and income levels. Thus, the study could analyze the impact of these variables on WTP for individual noise policies. The main characteristics of the survey participants are shown in Table 4. Individuals who were between 20 and 59 years of age accounted for 52.3% of the total respondents. The largest proportion of respondents was in their 30s (33.0%). A monthly household income of more than KRW 5 million was the most common income, at 41.7%.

Table 5 shows the results of the questionnaire responses to the CVM items related to the traffic noise reduction policy. The number of individuals who indicated that they were

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[7] In the survey, respondents were informed that the government is now preparing various noise reduction measures, including installing soundproof walls next to the road, low-noise pavement, and soundproof facilities. After the policy is implemented, the noise can be reduced up to the level where people do not feel any annoyance at noise (see Appendix Table 8).

[8] The pre-test was conducted on 400 people aged 20 to 65 years in Seoul, Gyeonggi, and six metropolitan cities through an online survey. A total of 387 questionnaires were completed, excluding the results that were not answered correctly.

Table 3 Initial bid and the number of sample respondents in the CVM survey

Initial bid (traffic noise)	Number of respondents	%
KRW[1] 1000	218	21.3
KRW 3000	199	19.5
KRW 8000	191	18.7
KRW 12000	212	20.7
KRW 20000	202	19.8
Total	1022	100

[1] According to the Bank of Korea (https://www.bok.or.kr), US $1 equaled to KRW 1113.50 in September 2018

willing to pay the initial amount decreased as the amount gradually increased.

Empirical results

A survey was conducted to determine if the respondents were willing to pay a given amount of money to achieve the noise level required to eliminate their annoyance at noise. Table 6 shows the estimation results. Among 1022 samples, we considered the 605 respondents who could hear road/railway noise or see roads/railways from their house. Based on the model without covariates, we found that respondents were willing to pay an average of KRW 6752.65 to not suffer from the stress or annoyance caused by traffic noise from roads and railways. This is the inconvenience cost of traffic noise.

An additional analysis was conducted to examine the effects of several variables on respondents' WTP. We considered respondents' socio-demographic characteristics, their annoyance levels, and the average noise level of their location. In the first model, we used the following variables: bid, household income, number of children, annoyed, extremely annoyed[9], and a constant. In the survey, the respondents had to select how annoyed they were by road traffic noise in their daily lives. The answers consisted of five options on a 5-point Likert scale: extremely un-annoyed, slightly un-annoyed, neutral, annoyed, and extremely annoyed. In the second model, we used similar variables as those used in the first model. However, the real noise level of the respondent's living area was added to the second model. By multiplying the noise level by the annoyance at noise, we created two new variables: "noise × annoyed" and "noise × extremely annoyed." This allowed the second model to calculate the WTP contained in the noise level of the respondent.

Table 7 shows the estimation results for models with covariates. In Model 1, the coefficient of estimation for all variables except for the number of children was statistically significant. When the degree of annoyance increased from "annoyed" to "extremely annoyed," the estimation coefficient increased by 0.25. Thus, the amount of the payment for eliminating the annoyance increased from KRW 8422 to KRW 9848 as the level of annoyance at noise increased. In Model 2, which considered the level of road traffic noise in the respondent's living area, the coefficient of estimation for the number of children was insignificant and the other covariates were statistically significant at a 5% significance level. It is worth noting that people with the highest degree of annoyance (extremely annoyed) were willing to pay a slightly larger amount for the noise reduction policy than those who had a lower annoyance (annoyed) when they were exposed to the same noise as the others. In other words, individuals who are extremely annoyed at the noise were willing to pay approximately KRW 6040 for the policy, whereas the others were willing to pay approximately KRW 6022 at the same noise level.

Table 4 Demographic characteristics of respondents

		Number of respondents	%
Total		1022	100
Sex	Male	534	52.3
	Female	488	47.7
Age	20–29 years	225	22.0
	30–39 years	337	33.0
	40–49 years	284	27.8
	50–59 years	176	17.2
Monthly income levels (million KRW)	Less than 2.99	221	21.6
	3.00–3.99	172	16.8
	4.00–4.99	203	19.9
	More than 5.00	426	41.7

Economic benefits of traffic noise reduction policies

Based on the estimation results in the "Empirical results" section, we analyzed the economic benefits of a noise reduction policy. We established a scenario where policies would be implemented to reduce the noise level experienced by respondents in their respective regions to an appropriate level at which the annoyance is eliminated. In other words, the study estimates the economic benefits and total costs when a policy that makes the degree of annoyance equals to zero is implemented. To estimate the benefit of the policy, three values are needed: the amount of reduction in noise, the annual WTP for reducing noise by 1 dB(A), and the total number of households in the country.

First, this study investigated the annual average transportation noise in the respondents' living areas[10] in 2016. To

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[9] The two variables of "annoyed" and "extremely annoyed" are set as dummy variables, with a value of 1 when the respondent is annoyed or extremely annoyed because of road traffic noise.

[10] We matched the noise level of respondents' living area based on national noise information system in Korea (www.noiseinfo.or.kr/). The average noise level is 67.53L_{dn}.

Table 5 Response distribution in the CVM survey

Initial bid amount	YY	YN	NY	NN	Total
KRW 1000	75	39	11	93	218
KRW 3000	35	39	20	105	199
KRW 8000	21	29	21	120	191
KRW 12000	21	26	28	137	212
KRW 20000	9	22	22	149	202
Number of responses	161 (15.8%)	155 (15.1%)	102 (10.0%)	604 (59.1%)	1022 (100.0%)

estimate the average noise level, we used the unit of L_{dn}[11] or L_{den}[12]. L_{dn} is referred to as day–night average sound level. In the day–night average sound level (L_{dn}), L_d and L_n are the average values of A-weighted noise from 06:00 to 22:00 and from 22:00 to 06:00, respectively. Conversely, L_{den} is referred to as the day–evening–night average sound level, which was proposed by the European Commission (2002). To calculate the day–evening–night average sound level (L_{den}), L_d, L_e, and L_n are defined as the average values of A-weighted noise from 07:00 to 19:00, from 19:00 to 23:00, and from 23:00 to 07:00, respectively. The difference between L_{dn} and L_{den} is used to define the time zone.

Because the timing of measuring noise in Korea is divided into two parts, daytime (06:00~22:00) and nighttime (22:00~06:00), we used L_{dn} to calculate the daily average noise level. First, we calculated the average transportation noise levels across the country in 2016 by using the data from the NNIS. After calculating the average noise level by region, we matched the respondents' living areas with their noise data. Then, we determined the average transportation noise level of the residents, $67.53L_{dn}$.

According to the previous studies described in the "Dose–response relationships between noise and annoyance" section, annoyance at noise over $42L_{den}$ is known to limit daily activities, decrease productivity, and increase psychological discomfort. Finally, we obtained a value of 25.53 dB(A) because the current noise level of $67.53L_{dn}$ must be decreased to $42L_{den}$ to remove the annoyance.[13]

The second value required to estimate the benefit is the amount of annual average WTP per 1 dB(A). As shown in Table 7, individuals who were annoyed and extremely annoyed by noise reported that they would pay an annual average of KRW 8422 and KRW 9848, respectively, to eliminate their annoyance. The respondents with no annoyance at noise were willing to pay an annual average of KRW 2627, represented by the constant term. Approximately 72% of the total respondents did not feel annoyed by the noise, whereas 23% and 5% of respondents were annoyed and extremely annoyed, respectively, at noise. Therefore, we calculated the weighted average of the payment amount as KRW 4320.9 (US $ 3.87) per year, according to the respondents' degree of annoyance.

The last step of the policy scenario is to convert the amount of individual payments into the amount of payments for the entire country by using the total number of households. In 2016, the total number of Koreans and the total number of households in the nation were 51.26 million and 19.37 million, respectively.

Finally, these three values were used to obtain the economic benefits of policy implementation in the scenario. We divided the amount of annual payment for annoyance removal, KRW 4320.9, by the amount of change in noise, 25.53 dB(A), because we wanted to determine the economic benefits as the value per 1 dB(A) decrease in noise. Then, we multiplied this value by the total number of households in Korea, 19.37 million, to expand from one household to the nation. The total benefit of the policy to remove annoyance in Korea is estimated to be approximately KRW 3.28 billion (US $2.91 million) per 1 dB(A) decrease.

This study also calculated the total cost of a noise reduction policy in addition to its economic benefits. Technical methods to reduce noise levels include the installation of soundproof walls and low-noise pavement. According to the Korea Development Institute, the cost of installing a sound barrier to reduce noise by 1 dB(A) is KRW 8402 per meter per year (KDI 2002). As of 2016, there were 1678 km of newly

Table 6 Estimation results for the willingness to pay (WTP) model (without covariates)

Variables	Coefficient estimates (*t* values)
Constant	0.2059 (2.084)*
Bid amount	0.00012 (17.36)***
Mean WTP (KRW)	6752.65
Number of respondents	605
Log-likelihood	− 736.35

*, *** indicate statistical significance at the 5%, and 0.1% levels, respectively

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[11] $L_{dn} = 10\log\left[\frac{1}{24}\left\{16 \times 10^{\frac{L_d}{10}} + 8 \times 10^{\frac{L_n+10}{10}}\right\}\right]$ (Kim et al. 2006)

[12] $L_{den} = 10\log\left[\frac{1}{24}\left\{12 \times 10^{\frac{L_d}{10}} + 4 \times 10^{\frac{L_e+5}{10}} + 8 \times 10^{\frac{L_n+10}{10}}\right\}\right]$

[13] L_{dn} and L_{den} are considered to be the same units representing the average noise per day in this study.

Table 7 Estimation results of the willingness to pay (WTP) in Models 1 and 2

Variables	Model 1			Model 2		
	Coefficient estimates		WTP (s.d.)	Coefficient estimates		WTP (s.d.)
Bid amount	0.00012	***	–	0.00012	***	–
Household income	0.123	**	6537.05 (474.60)	0.124	**	6540.62 (474.21)
Number of children	0.187	.	6834.84 (621.04)	0.189	.	6842.84 (620.74)
Annoyed	0.501	*	8422.49 (1115.17)	–		–
Extremely annoyed	0.755	*	9848.12 (1990.39)	–		–
Noise × annoyed	–		–	0.0075	*	6021.82 (392.62)
Noise × extremely annoyed	–		–	0.0112	*	6039.91 (391.77)
Constant	− 1.034	**	2627.70 (789.99)	− 1.039	**	2617.38 (790.01)

The unit is Korean won. . , *, **, *** indicate statistical significance at the 10%, 5%, 1%, and 0.1% levels, respectively

s.d. standard deviation

installed roads with soundproof walls nationwide (Ministry of Environment 2017). In addition, the cost of low-noise pavement is KRW 1903 per meter per 1 dB(A) reduction (Seoul Department of Road Management 2010). The total length of domestic low-noise pavement is 483 km (Ministry of Environment 2017). We then calculated how much money was used in 2016 to lower traffic noise by 1 dB(A). The total cost can be obtained by multiplying the costs of pavement with a sound barrier and low-noise pavement by the total length of each extension. That total cost is KRW 15.0 billion (US $13.36 million) per year, which is greater than the benefit for residents.

Conclusion and remarks

Environmental quality is a critical factor in quality of life. Long-term exposure to noise increases the incidence of cardiovascular and hypertensive diseases as well as hearing loss. The Korean government has made efforts to improve the surrounding environment, including air quality, water quality, soil quality, and environmental noise. Many researchers have carried out studies to aid in implementing robust policies aimed at reducing environmental pollution. For example, Giovanis and Ozdamar (2018) found that the willingness to pay for improvements in air quality, especially reductions in SO_2 and O_3, and the economic value of pollution reduction implies that policymakers should not ignore air pollution. With this perspective, we conducted this study on one of the most serious types of pollution globally, noise pollution. Among the various types of noise, traffic noise can last for a long time and become chronic, resulting in serious consequences for the human body. Road traffic noise is the most frequent form of environmental pollution in everyday life and is also felt most directly. Although studies on the benefits of road traffic noise reduction have been actively conducted in Korea since 2000, few studies have focused on the annoyance at transportation noise.

Therefore, this study is distinctive because it was conducted to investigate how respondents' willingness to pay changes according to their number of children, household income, and degree of annoyance with traffic noise in Korea. Moreover, we measured the degree of social costs and benefits when the annoyance of the individual is eliminated. The study found that individuals who are annoyed and extremely annoyed by traffic noise are willing to pay an annual average of KRW 8422 and KRW 9848, respectively. In the scenario analysis of noise reduction policy in the "Economic benefits of traffic noise reduction policies" section, the economic benefit obtained by making noise-related annoyance equal to zero is roughly KRW 3 billion, which is five times less than the total cost of KRW 15.0 billion. However, the gap between cost and benefit will narrow as the technology for noise reduction develops, which will decrease the costs of implementing soundproof systems. If future studies consider not only annoyance but also other mental diseases and physical disorders caused by traffic noise, the benefits of a noise reduction policy also would increase.

In addition, one of the implications of this study is related to the characteristics of annoyance from traffic noise. Generally, a change of annoyance follows a polynomial function instead of a linear function (see the left side in Fig. 1). Unlike transportation noises from roads and railways, wind turbine noise, industrial noise, and air vehicle noise occur relatively unregularly, which makes the slope steep. However, a change of annoyance at transportation noise, which occurs regularly, also has a relatively moderate increasing shape along the polynomial approximation, which is not

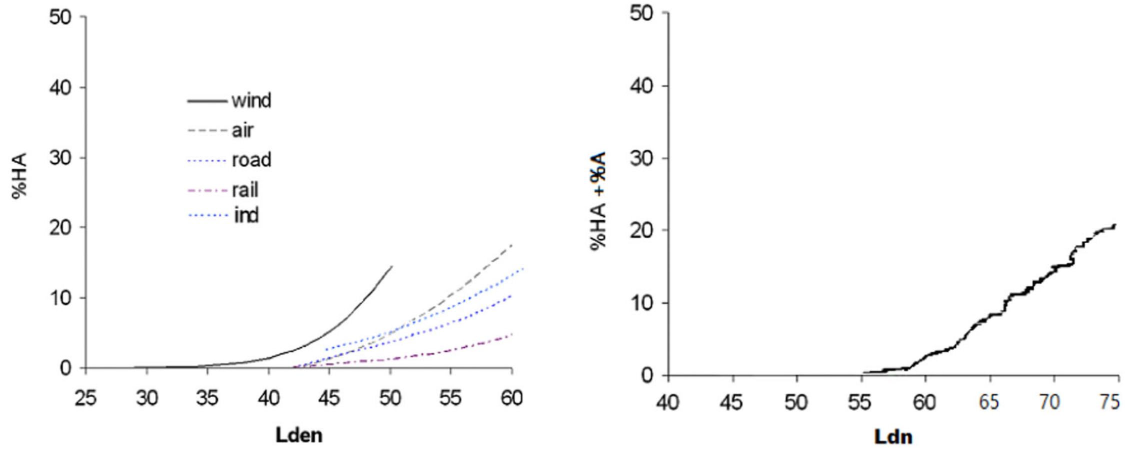

Fig. 1 The left figure shows the percentage of residents who are highly annoyed (%HA) due to wind turbine noise (wind), air, road, rail, and industrial noise (ind). The right figure shows the percentage of residents who are highly annoyed (%HA) or annoyed (%A) due to transportation noise in this study. (Source: Janssen et al. 2011)

linear. Based on the survey results of this study and noise information about respondents' living area, we could analyze the relationship between respondents' annoyance and noise levels (L_{dn}) (see the right side in Fig. 1). As a result, the slope of a percentage of residents who are annoyed or highly annoyed tends to be steep as the noise level goes up. This is consistent with the results of previous studies (Ragettli et al. 2015; Michaud et al. 2008; Schultz 1978; Miedema 2007; Klæboe et al. 2004; Kim et al. 2006; Ali 2010; European Commission 2002; European Environment Agency 2010). In addition to the fact that the change of annoyance follows a polynomial function, the variations in annoyance levels from traffic noise can be large, depending on the respondents' living area. Therefore, policymakers should consider the characteristics of living areas and variation of annoyance levels when establishing effective traffic noise reduction policies.

Indeed, many other countries have taken measures to reduce noise while accounting for the concept of annoyance. For example, Germany established limits for the level of railway noise based on annoyance in the Traffic Noise Ordinance from 1990. Recognizing that the degree of annoyance caused by railway noise is lower than that caused by the same noise level of other noise sources, the German legislature established limits for railway noise adjusted by − 5 dB (International Institute of Noise Control Engineering 2009). The Austrian legislature also enacted noise limit standards in terms of annoyance at noise in 1993 (International Institute of Noise Control Engineering 2009). Furthermore, the noise policies of US federal agencies are based on an annoyance fitting function that was proposed by the US Federal Interagency Committee on Noise so that the agencies could consider the general adverse reaction (annoyance) of people to noise in noise reduction policy making. Kim et al. (2006) compared the two scores after calculating the percentage of residents who were highly annoyed (%HA) based on the noise standards of Korea and Japan. As a result, %HA corresponding to the Korean noise standard was higher than %HA of Japan, but noise standards were applied more strictly in Japan than in Korea. Therefore, it is necessary to revise environmental and regulatory standards with a deep understanding of annoyance. However, the Korean government has yet to pay close attention to health effects such as annoyance, sleep disturbance, and cardiovascular disease at the stage of designing and implementing noise reduction policies.

In addition, a previous study showed that Koreans are generally more annoyed than others from different countries at the same transportation noise levels (see Fig. 2). Overall, considering the fact that Koreans are more sensitive to noise than other countries, this study confirms that Koreans have a willingness to pay as a financial sacrifice for noise reduction policies. In addition, as the noise level increases, the degree of annoyance also increases much more than the increase of noise and annoyance, although this varies depending on where the residents live. To date, research has been limited to physical studies focusing on traffic noise reduction. Therefore, it is necessary to establish a policy considering annoyance in each region because Koreans are relatively more sensitive to traffic noise than others. The results of this study can be used as basic data for defining the economic relationship between noise and annoyance in considering the uncomfortable effect of traffic noise on future environmental impact assessments. Again, this study is meaningful because it estimates how much people with an annoyance at existing traffic noise problems are willing to pay and also derives various implications, such as the economic costs and benefits of a virtual policy based on the estimation.

This study has some limitations. First, the study did not confirm the dose–response relationship between annoyance and noise but instead extracted the relationship from several previous studies. Future studies should investigate changes in

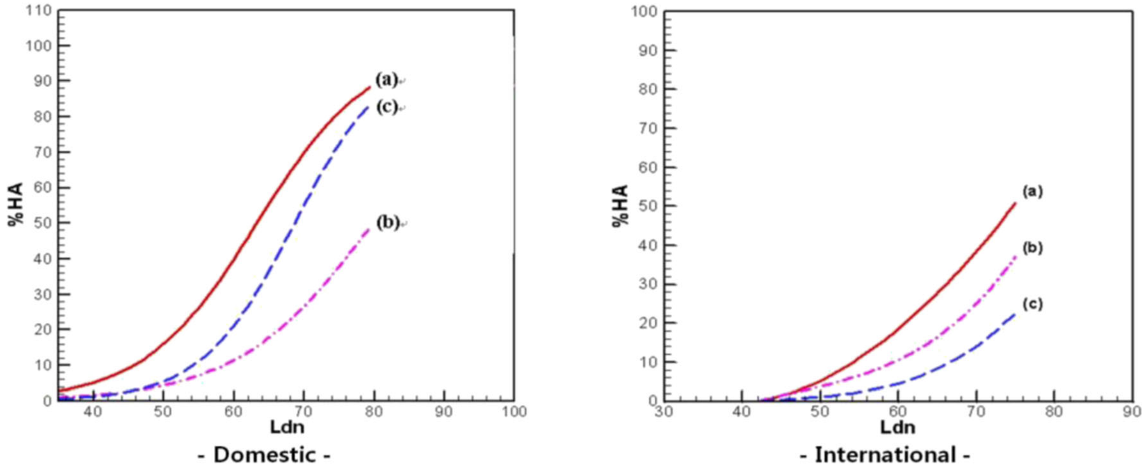

Fig. 2 A comparison between the percentage of residents who are highly annoyed (%HA) by (**a**) aircraft, (**b**) road traffic, (**c**) railways in domestic (Korea) and international cases at the same noise level. (Source: Lee et al. 2005)

the level of annoyance with traffic noise by segmenting noise sources and combining CVM studies and their dose–response relationships. Second, the method of measuring noise levels at specific points and presenting them as the representative noise level of the area cannot sufficiently reflect variations of noise in a given area. Third, this study used a reference noise level of $42L_{den}$, which is the level to remove annoyance. In Korea, the timing of measuring traffic noise is divided into daytime (06:00–22:00) and nighttime (22:00–06:00). However, in most countries, traffic noise is measured at daytime, evening, and nighttime. Therefore, the unit of the daily average noise level in Korea is different than that of other countries. Future studies should identify important aspects of eliminating noise-related annoyance according to the characteristics of each country.

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Appendix

The Contingent Valuation Method (CVM) establishes a virtual situation in which decisions can be made regarding the use of environmental goods; in addition, it evaluates the value of environmental goods by analyzing the results of surveys of individual choices under these circumstances. This method has been widely used for the evaluation of environmental properties such as landscapes, wetlands, and forest protection as well as policy evaluation related to improvements in environmental quality, such as water quality and air pollution, by directly questioning the value of environmental goods to individuals

However, CVM has a number of limitations in the process of questionnaire production, sample selection, questionnaire surveys, data coding, and analysis. First, biases due to incentives to misrepresent responses, such as a strategic bias, can occur in CVM. This happens when a respondent expresses a willingness to pay to pursue his or her own interests. As a result, the potential users of the goods will be influenced by the respondents' intentions. Second, biases due to implied value cues, such as a starting point bias, exist. Biases due to implied value cues appear when the respondent understands that the value cues for the various values presented in the survey refer to indicative information about the willingness to pay or a number representing the item being assessed. In particular, starting point bias occurs when the respondent considers the initial bid amount to be information on the real value of the goods (Boyle and Bishop 1988). Third, context misspecification bias occurs when an error is made in the provision of information in the context of the questionnaire scenario; therefore, the respondent does not answer the questionnaire according to the intention of the researcher. Examples include elicitation question bias or question order bias.

Two important criteria for judging the success of CVM sequencing are validity and reliability. When the CVM study estimates that it was intended, the estimate is said to be valid and reliable when the estimate is consistent (Hoevenagel 1994). However, if the actual WTP for the estimated target value is unknown, it is difficult to determine whether or not the bias occurs in the CVM estimation result and how much the bias will be. Although it is not possible to calculate how much the effect to eliminate the bias has reduced, the reliability and validity of the estimation result will be enhanced conceptually due to efforts to reduce bias of the CVM study. The six US National Oceanic and Atmospheric Administration (NOAA) panels, headed by Arrow, presented a NOAA panel report indicating that CVM methodology is useful when the CVM survey is conducted properly (Arrow et al. 1993). This report provided an important opportunity for the CVM methodology to be credible.

Table 8 Description of noise environment

Definition and classification of noise	1) Noise is defined as an unwanted sound that is a detriment to the pleasant living environment of a human being. 2) Noise is largely divided into living noise and traffic noise. – Living noise is from apartments, buildings, or construction sites. – Traffic noise includes road traffic noise, aircraft noise, and railroad noise.
Damage or impact of noise	1) With the growth of urbanization and population, construction sites in urban areas have been increasing. In addition, because the number of vehicles and roads is also growing, most of the population in Korea is exposed to traffic noise almost every day of the year. 2) If you are exposed to high levels of noise, it may cause annoyance, discomfort, and sleep disturbances. 3) If you are exposed to noise continuously, then the likelihood of cardiovascular disease and hypertension tends to be higher.
Regulations related to noise	1) The Korean government has regulated noise levels via the Noise and Vibration Control Law, which has different standards during night and day. 2) However, according to the measurements made by the National Noise Network, the noise levels in most areas exceed the standards.
Issues related to noise reduction measures	1) The government is now preparing various noise reduction measures. Specific noise reduction measures to reduce traffic noise include the installation of soundproof walls and the low-noise paved roads. In addition, measures for reducing living noise include the use of building materials to prevent noise from the floor and the installation of soundproof facilities in construction areas. 2) These measures to reduce noise can eliminate an individual's annoyance at noise. 3) However, implementing noise reduction policies can be costly.
The purpose of this study	Some of the costs to implement noise reduction policies can be covered by an additional income tax that you pay. If you do not pay the cost, then it is difficult to implement policies and you may incur damage due to noise. Otherwise, you can live in a pleasant environment without traffic noise. Therefore, the purpose of this survey is to identify the additional income tax that you are willing to pay to implement noise reduction measures.

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