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Annoyance due to residential road traffic and aircraft noise: Empirical evidence from two European cities

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A B S T R A C T

Based on a study in two European cities, Mainz in Germany and Zurich in Switzerland, the article investigates both acoustical and non-acoustical factors affecting indoor annoyance due to residential road traffic and aircraft noise. We specifically focus on three factors: (1) the role of windows as a feature of the building where people live; (2) the role of individual environmental concern as a general attitude; and (3) the role of household income as an indicator of socioeconomic resources. Empirical results show that closed windows in general and closed high-quality windows in particular are an important barrier against outdoor road traffic and aircraft noise, as well as a helpful subjective coping tool against corresponding annoyances. Environmental concern, too, proves to be a significant predictor of noise annoyance. Environmentally highly concerned people articulate feelings of annoyance more often than environmentally less concerned ones. As expected income is negatively related to road traffic noise annoyance. However, we find a positive association of income with annoyance from aircraft noise. Although objective exposure to aircraft noise is lower for high-income households, they feel stronger annoyed by noise from airplanes. Income shows various indirect effects on noise annoyance. A comparative analysis of road traffic and aircraft noise annoyance yields similarities, but also remarkable differences in terms of their influence factors.

Keywords:

Noise annoyance

Noise exposure

Noise protection

Environmental concern

Household income

1. Introduction

A large fraction of the European population is exposed to noise levels above the limits recommended by the World Health Organization WHO (2018). It is well known that long-term ambient noise has serious negative impacts on people's subjective well-being and personal health. Numerous studies indicate that high noise levels cause adverse feelings of annoyance, sleep disturbance, high blood pressure, cardiovascular diseases, cognitive impairment in children, and other health issues (e.g. Basner et al., 2014; Viennau et al., 2015; European Environmental Agency EEA, 2020; Münzel et al., 2021). The most recent EEA report (2020) on "Environmental Noise in Europe" estimates an annual incidence of 12,000 premature deaths, 48,000 cases of ischemic heart disease, and 22 million Europeans suffering from "chronic high annoyance." The latter reaction to noise exposure – subjective noise annoyance – is the topic of this paper. We restrict our attention to residential noise.

Ample research shows that feelings of annoyance caused by residential road traffic noise, aircraft noise, and other sources of neighborhood noise depend on both acoustical and non-acoustical factors (e.g. Fields, 1993; Guski, 1999; Miedema and Vos, 1999; Miedema and Oudshoorn, 2001; Ouis, 2001; Marquis-Favre et al., 2005; Miedema, 2007; Brink et al., 2019). The most important acoustical factor is the objective exposure to noise, predominantly measured as the day-evening-night level (Lden). The most prominent non-acoustical factor is noise sensitivity, usually seen as a personality trait.

In both groups of factors, however, there are additional influences that have been proven or suggested to be significant predictors of noise annoyance. Brink et al. (2019), for example, introduced a measure called Intermittency Ratio as an additional acoustical factor. Noise can come as a continuous flow, or it can come with shorter or longer interruptions, and this may have an effect on subjective responses. When we are interested in indoor noise annoyance caused by outdoor noise exposure, it seems reasonable to subsume also factors such as the sound insulation of a building, a quiet side of the dwelling or the quality of windows within the group of acoustical factors (Miedema, 2007: 49).

The list of additional non-acoustical factors, most often individual attributes, is even longer than that of the acoustical ones (Fields, 1993; Guski, 1999; Miedema and Vos, 1999; Lefèvre et al., 2020). Besides sociodemographic variables (gender, age, etc.), attitudes toward the noise source have been shown to be relevant for annoyance responses. Fear of harm connected with the noise source, individual coping capacity, and expectations of the future noise development are other non-acoustical factors within the debate and the corresponding research.

While taking into account the well-established main predictors of indoor noise annoyance (via techniques of statistical control), new studies should adopt the strategy of focusing on specifically selected single factors that are promising candidates for fresh and new insights. Following this strategy, we will concentrate on three aspects, which have not found sufficient attention in past annoyance research: (1) the role of windows as a feature of the building where people live; (2) the role of individual environmental concern as a general attitude; and (3) the role of household income as an indicator of socioeconomic resources. While (1) belongs to the group of acoustical factors, (2) and (3) belong to the group of non-acoustical factors.

Exposure to residential noise is usually assessed at selected façade points of the building, which means outdoor noise. At a given level of outdoor noise, however, noise levels indoor can vary greatly. For living comfort, subjective well-being, and health effects, indoor rather than outdoor noise is crucial, and there are more or less effective possibilities to prevent external noise from intruding into the building and thus becoming subjectively annoying. In recent decades, considerable progress has been made concerning the sound isolation of buildings (e.g. McMullan, 2018). Technological innovations particularly pertain to the quality of windows because windows are the weak spots, i.e. the most evident gateway of noise inflow. While there are various industry standards for windows with minimum requirements, modern high-quality soundproofed windows can absorb high noise levels, including potentially annoying road traffic and aircraft noise. We conclude from the literature that psychological noise annoyance research did not appropriately catch up with the new technological developments in the field of noise insulation. In this article, therefore, we will explore the role of windows in reducing noise annoyance in general, and the role of high-quality windows in particular. Our baseline hypothesis is that windows are an important barrier against outdoor residential noise, and serve simultaneously as a subjective coping tool with noise. Closing windows can actually reduce indoor noise, and it may additionally be important for the subjective evaluation of the capacity to cope with noise (with windows as a tool to control the noise situation).

Our second special topic, the role of individual environmental concern, does not pertain to technological changes but to societal ones. Looking at the public and scientific debate about noise exposure and annoyance, we can observe a shift in the problem-definition and problem-framing in the direction of noise as an environmental protection issue. Whereas an environmental framing of noise has not always played an important role, the growing environmental awareness of the general public and the increasing political attention to environmental protection have contributed to categorizing noise issues under the broader umbrella of environmental problems. There is an ongoing discussion within noise research that the established dose-response curves for road traffic, aircraft, and railway noise have shifted upward in recent years, i.e. that, at a given level of noise exposure, people are more highly annoyed today than they were three or four decades ago (e.g. Babisch et al., 2009; Gille et al., 2016; Guski et al., 2017; Lefèvre et al., 2020). We can only speculate about the reasons for this upward shift. Due to extensive research on the detrimental effects of noise on human health and due to the media coverage of this research, an increasing share of the population may have become aware of the fact that the burden of noise is more than an uncomfortable nuisance. Similar to second-hand smoking, the public may take information on the negative health effects of noise more seriously than in the past.

A related reason for this increased "noise aversion," which is still controversial (see, Gjestland, 2020), could be the stronger environmental concern of the population. In line with the growing environmental framing of noise, we should find at the individual level that – holding other influence factors constant, including noise exposure – environmental concern yields a positive effect on noise annoyance. This is exactly the hypothesis of our empirical analyses. Within the context of noise research, environmental concern can be subsumed within the rubric of attitudinal factors influencing noise annoyance. Many noise studies examined effects of specific attitudes on noise annoyance, mainly attitudes and evaluations directly pertaining to the noise source itself. Environmental concern, however, is a general attitude pertaining to affective worries about environmental protection, to cognitive insights into the endangerment of the environment, and to conative support for environmental action (for this attitude concept of environmental concern, see e.g. Diekmann and Preisendörfer, 2003; Franzen and Vogl, 2013). The general mindset of a high environmental concern can stimulate negative emotions toward noise as an environmental problem and thus result in stronger noise annoyance given the same level of noise exposure (Okokon et al., 2015).

Income and socioeconomic status are important resources for coping with noise, but their effects on noise annoyance are often not as strong as assumed (Fields, 1993; Miedema and Vos, 1999; Miedema, 2007). Fyhri and Klæboe (2006), for example, find a negative income effect in smaller Norwegian cities but not in Oslo, the capital of Norway. The authors point out that Oslo as an urban center is both attractive and noisy. They further hypothesize that high-income people have better chances "to buy themselves out from noise," and more so in smaller than in big cities. In a French study, Padilla et al. (2014) report on a positive income effect on noise exposure in Paris, but find a reversed effect in Marseille. The noisy harbor area in Marseille is inhabited by low-income households, while the inner city of Paris attracts rich households with urban lifestyles. Thus, whether there is a relation between income and noise exposure depends on local features. Additionally, there are other channels of indirect income effects on noise annoyance. The "environmental shielding hypothesis" (Diekmann et al., 2021) focuses on how high-income households cope with noise and suggests several possibilities of noise protection. Sufficient income resources enable households to shield themselves against noise by using soundproofed high-quality windows. Apartments of resourceful households are usually larger than those of low-income households. Apartment size is important for locating living spaces and bedrooms away from road traffic noise (Babisch et al., 2014). Noise annoyance may also be lower when people can retreat to green spaces, for example to a backyard garden. Finally, there might be a positive association between income and noise sensitivity, partly compensating the supposed negative income effect on noise annoyance.

To investigate the role of our three special factors (windows and their quality, environmental concern, household income), we will – with the intention of performing a "double cross-check" – look at residential road traffic noise on the one hand and residential aircraft noise on the other, and we will comparatively analyze two cities, Mainz in Germany and Zurich in Switzerland. It is well known in noise research that road traffic and aircraft noise are different, both in their acoustical features and in their subjective perceptions and evaluations (e.g. Miedema and Oudshoorn, 2001; Miedema, 2007). Given the same level of Lden, subjective annoyance due to aircraft noise is usually higher than the corresponding annoyance due to road traffic noise. In addition, the effects of other annoyance predictors are partly different for road traffic and aircraft noise. For our empirical analyses, we expect that windows, and high-quality windows in particular, protect better against road traffic than against aircraft noise. A dwelling with more rooms and a backyard garden can contribute to lower annoyance values in the case of heavy road traffic noise, but less so in the case of heavy aircraft noise. If aircraft noise is present in a neighborhood, it is "all over the place" (affecting all façades of a building in the same way) and can come with high maximum sound pressure levels that even top-quality windows cannot fully absorb. This implies that closing the windows of the dwelling, and closing high-quality windows in particular, should reduce road traffic noise annoyance more strongly than aircraft noise annoyance. Based on this, aircraft noise may be connected with stronger emotional arousal than road traffic noise, and we therefore expect that environmental concern will have a stronger effect on annoyance from aircraft than from road traffic noise.

A comparative analysis of two cities allows checking the stability of findings in different contexts. Comparing the two selected cities, Mainz and Zurich, is empirically meaningful, especially with respect to aircraft noise. Both cities are located near international airports. Mainz (with 210,000 inhabitants) is affected by Frankfurt Airport, which is about 25 km east of the city. Zurich (the largest city in Switzerland, with 430,000 inhabitants) is affected by Zurich Kloten Airport, which is about 10 km north of the city. Aircraft noise has been a controversial public issue in both cities for many years (for Mainz, see e.g. Schreckenberg et al., 2010; Wiebusch, 2014; for Zurich, see e.g. Wirth, 2004; Bröer and Duyvendak, 2009). In Mainz as compared to Zurich, however, the aircraft noise issue was much more salient at the time of our study. Since 2011, there are regular protest rallies of environmental groups against Frankfurt Airport, which are also supported by the city authorities of Mainz (FAZ, 2019). Based on this stronger salience, we predict a positive city effect of Mainz on aircraft noise annoyance, even after controlling for noise exposure. For road traffic noise annoyance, however, we do not have plausible arguments to expect city-specific differences. Since both cities are growing and have a dynamic economy, they are confronted with the typical problems caused by having "too many cars." Furthermore, both cities try hard to curb the dominant role of cars in the city center.

The rest of the paper is structured as follows. In the next section (Section 2), we describe the data gathered in Mainz and Zurich and our dependent and independent variables. The first part of empirical results (Section 3) reports descriptive findings. The second (Section 4) turns to multivariate results of ordinary least square regression models for indoor annoyance due to road traffic and aircraft noise. A discussion and conclusions section (Section 5) closes the paper.

2. Data and variables

2.1 Empirical data

The main data for our empirical analyses come from surveys in the city of Mainz and the city of Zurich. Data were gathered as part of a project supported by the German Research Foundation (DFG) and the Swiss National Science Foundation (SNSF). With the exception of some local adaptations, the surveys in the two cities were strictly comparable in terms of both research design and question program. The surveys were carried out as mail questionnaires and were conducted between October 2016 and March 2017.

The surveys were based on random samples of the adult population (aged 18 to 70) in Mainz and Zurich. The addresses of the random samples came from the official population registers managed and maintained by the city administrations (Einwohnermeldeamt in Mainz, Einwohnerregister in Zurich). The samples did not only include people of German or Swiss nationality, but also foreigners living in the cities. Because we had the exact address of our respondents, we were additionally able to locate the spatial coordinates of their places of residence. The coordinates enabled us to match administrative noise data to the survey data (Section 2.2).

Subjects selected for participation in the study were approached following the tailored design method of Dillman et al. (2014); that is, they received a first invitation to participate in the survey, a postcard after one week, a second invitation after three weeks, and a third invitation after seven weeks. The University of Mainz and the ETH Zurich organized the fieldwork, and the respondents could clearly recognize this via the cover letter and the questionnaire. It is important to note that – to prevent selectivity of the samples on the dependent variables – the surveys were not introduced as an environmental survey, but as a survey entitled "Housing and Living in [Mainz/Zurich]."

In Mainz, the mail survey started with 4,000 addresses, leading ultimately to 1,800 completed questionnaires. This is a raw response rate of 45 percent. The corresponding figures for Zurich are 4,000 starting addresses and 1,931 successfully realized questionnaires – a raw response rate of 48 percent. Taken together, the combined number of cases for the two cities is 3,731 (for methodological details of the study, including issues of sample selectivity, see Bruderer Enzler et al., 2019).

Due to missing values and the exclusion of some cases from the beginning, this combined number is lower for our following analyses. For the multivariate models, we will use only complete cases – that is, cases with valid values for all variables.

2.2. Dependent and independent variables

Our crucial dependent variables are road traffic and aircraft noise annoyance in the dwelling. Based on the topics of interest in this article, the most important independent variables are exposure to road traffic and aircraft noise, the quality of the windows of the dwelling, environmental concern, and income. Additionally, we have a set of covariates that mainly serve as control variables for the multivariate models. In this section, we merely describe the measurement of these variables without descriptive statistics, as these will be given in the later sections on empirical results.

For the measurement of noise annoyance, we used the 11-point scale, ranging from "0 = not annoyed at all" to "10 = very much annoyed," which is recommended by the International Commission on Biological Effects of Noise ICBEN (Fields et al., 2001). However, we modified the wording of the ICBEN item. We did not ask respondents to think about the last 12 months when they were at home, but – without specifying a timeframe – to think about their situation at home under four different conditions. The question wording was as follows: "When you are at home in your dwelling, how strongly do you feel annoyed by road traffic noise (1) during the day when the dwelling's windows are open, (2) during the day when windows are closed, (3) during the night when windows are open, and (4) during the night when windows are closed?" The same sequence of four questions was presented for aircraft noise. Our special interest in the role of windows for noise annoyance motivated this kind of question format.

The noise exposure data were not gleaned from the survey, but from external sources, i.e. from administrative noise registers. As mentioned above (Section 2.1), the addresses of our respondents denoted their exact place of residence. We first determined the spatial coordinates for these locations. For Mainz, this geocoding was carried out using a web-based service that extracts coordinates from Google Maps. For Zurich, coordinates were taken from the Federal Register of Buildings and Dwellings. Subsequently, based on the coordinates, very fine-grained statistical data on local road traffic and aircraft noise were merged with the survey data. "Fine-grained data" means these data focus directly on the building where the respondents lived. Our matching of administrative noise data and survey data is tighter than that in most other studies – and this is a particular strength of our research. As already mentioned, we refer to Lden to capture the level of noise exposure. Lden measures noise exposure in decibels dB(A), gives a weighted 24-hours average, and applies the usual penalties for evening and nighttime noise (see Brink et al., 2018). More detailed information about our administrative noise data can be found in Appendix S1 of the supplementary material.

The quality of the windows of the respondent's dwelling was measured by the survey question "With respect to noise insulation, how would you assess the quality of the windows of your dwelling?" – with a 5-point response scale ranging from "1 = very bad" to "5 = very good." Of course, this is a subjective assessment that may not be fully valid in technological terms, but we see it as a viable proxy measure. An empirical hint supporting this proxy assumption is that respondents' assessments of the window quality and their estimates of the age of the building where they live correlate with $r = -0.24$ ($p<0.001$).

The measurement of environmental concern was based on six items of the environmental concern scale of Diekmann and Preisendörfer (2003). These items capture emotional, cognitive, and conative aspects of environmental awareness. Respondents were offered answers on a 5-point agree/disagree scale. An additive environmental concern index was constructed ranging from 1 to 5 (the sum of the items divided by 6). Details on the measurement of environmental concern are summarized in Appendix S2 of the supplementary material.

The average income in Germany (measured in Euro) is significantly lower than the average income in Switzerland (measured in Swiss Franc). We transformed our original variable "monthly net household income" in "monthly net equivalent household income," and to make it comparable between Germany and Switzerland, we converted Swiss Francs into Euros and accounted for the countries' different purchasing powers (PPP adjustment). In the following, we will call this variable simply "household income" or "income."

Our remaining independent variables, which mainly serve as statistical controls in the multivariate models, can be divided in two groups: (1) further factors characterizing the respondent's residence (in addition to Lden and window quality); and (2) further individual characteristics of the respondents (in addition to environmental concern and income).

With respect to the first group, we include the size of the respondent's dwelling, the binary information about whether the respondent's sleeping room is facing the street, and the binary information about whether the residence has its own garden. We expect that respondents with bigger dwellings, measured in m^2 (divided by 10), are less annoyed by outdoor noise because they have better opportunities of noise control simply by switching to a room that is more quiet. Respondents with a sleeping room facing the street are more often confronted with noise in the evening and at night, and we expect that this stimulates annoyance. A garden directly connected to one's residence is most often located in the backyard, and can thus serve as a place to escape from road traffic noise, but not from aircraft noise. It is therefore plausible to expect a negative garden effect on annoyance from road traffic, but no such effect on annoyance from aircraft noise.

Turning to the second group, we take into account the following variables: gender, age, age squared, education, labor force participation, ownership of dwelling, duration of living in the dwelling, noise sensitivity, own car use, and own air flights taken in the last year. The selection of these variables was mainly driven by findings of prior studies. Gender is a dummy with "1 = female." Age is measured in years (divided by 10). Some prior studies have found an inverted u-shaped age effect on noise annoyance (Miedema, 2007: 50), and therefore we include age squared. Education is captured in years of schooling. Labor force participation registers whether the respondent was "1 = employed or self-employed" at the time of the survey. Ownership of dwelling has the value of "1 = respondent is owner of the dwelling," as opposed to "0 = respondent is renting." Duration of living in the dwelling indicates since how many years the respondent has been living in his or her current dwelling. Because this variable shows a right-skewed distribution, we will use its natural logarithm (ln) for the multivariate models. As mentioned above, noise sensitivity is a personality factor that belongs to the top influences on noise annoyance. It was measured by an index of five items, which could be answered on a 5-point agree/disagree scale. These items, which are listed in Appendix S2, were adapted from Weinstein's noise sensitivity scale (Weinstein, 1978; Benfield et al., 2014). To capture own involvement in the production of noise, the models for road traffic annoyance include the variable "own car use," i.e. the information whether "1 = respondent drives their own private car." Correspondingly, the models for aircraft annoyance refer to the variable "own air flights taken in the last year," i.e. the information whether "1 = respondent reported taking one or more flights in the year preceding the survey."

Last but not least, the multivariate models control for the city, with “1 = Mainz” versus “0 = Zurich.” The city context cannot be qualified either as a factor characterizing the respondent’s residence, or as a factor pertaining to individual characteristics of the respondent.

3. Descriptive results

The WHO (2018) strongly recommends that the average road traffic noise level Lden should be lower than 53 dB, and the average aircraft noise level lower than 45 dB. The road traffic noise exposure Lden of our survey respondents is close to the WHO limit, both in Mainz (52.8 dB) and in Zurich (53.1 dB). The aircraft noise exposure Lden is above the WHO limit in Mainz (46.5 dB) and slightly below the WHO limit in Zurich (44.3 dB). An average road traffic noise level Lden of 60 dB or more applies for 22 percent in Mainz and for 20 percent in Zurich. The percentages of those facing an average aircraft noise level of 50 dB or more are 22 percent in Mainz and 7 percent in Zurich. Thus, there are no city differences with respect to road traffic noise exposure, but the share of the population exposed to high aircraft noise is higher in Mainz than in Zurich.[1]

Against this background of the noise exposure situation, Table 1 gives the percentages of those articulating feelings of high annoyance (%HA) due to road traffic and aircraft noise in Mainz and Zurich for the four constellations of day/open windows, day/closed windows, night/open windows, and night/closed windows. Following the usual procedure, those with codes 8-10 on the 11-point annoyance scale were coded as %HA.

Table 1

Percent highly annoyed due to road traffic and aircraft noise in Mainz and Zurich in four different constellations.

	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Road traffic noise in Mainz	16.6	3.2	13.2	3.4
Road traffic noise in Zurich	16.0	3.8	14.4	4.0
Aircraft noise in Mainz	24.6	10.5	21.4	9.8
Aircraft noise in Zurich	4.4	1.5	4.4	1.4

[1] The comparison of the aircraft noise level Lden between Mainz and Zurich should be approached with care because the modeling procedures used in Mainz and Zurich were not identical (as pointed out to us by local experts both in Mainz and in Zurich).

There are several remarkable patterns in Table 1. In accordance with the noise exposure situation, noise annoyance due to road traffic is very similar in Mainz and Zurich. Annoyance due to aircraft noise, however, is much higher in Mainz than in Zurich; again, this corresponds to the situation for noise exposure. Given the recurrent public debate about aircraft noise in Zurich, the %HA values for aircraft noise are remarkably low in the Swiss metropole (less than 5 percent). The %HA values for aircraft noise in Mainz, on the other hand, are worryingly high. Nearly a quarter of the adult population in Mainz articulates high annoyance due to aircraft noise for the constellation during the day, when the windows of the dwelling are open. Focusing on our research topic “windows and their quality,” the main finding in Table 1 is that there are considerable %HA differences between the situation of open and closed windows. Evidently, simply closing the windows of the dwelling can significantly reduce feelings of noise annoyance. When the windows are closed as compared to when they are open, the %HA decrease by a factor of about four for road traffic noise and a factor of about two for aircraft noise. Although the reduction is stronger for road traffic than for aircraft noise (as expected), we did not expect that the “windows effect” would be so strong.

Figures 1 and 2 show the relationship between Lden and %HA in the form of the well-known exposure-response curves. Figure 1 pertains to road traffic, and Figure 2 to aircraft noise in Mainz and Zurich. The four curves in each sub-graph differentiate the open versus closed windows constellations for day and night.

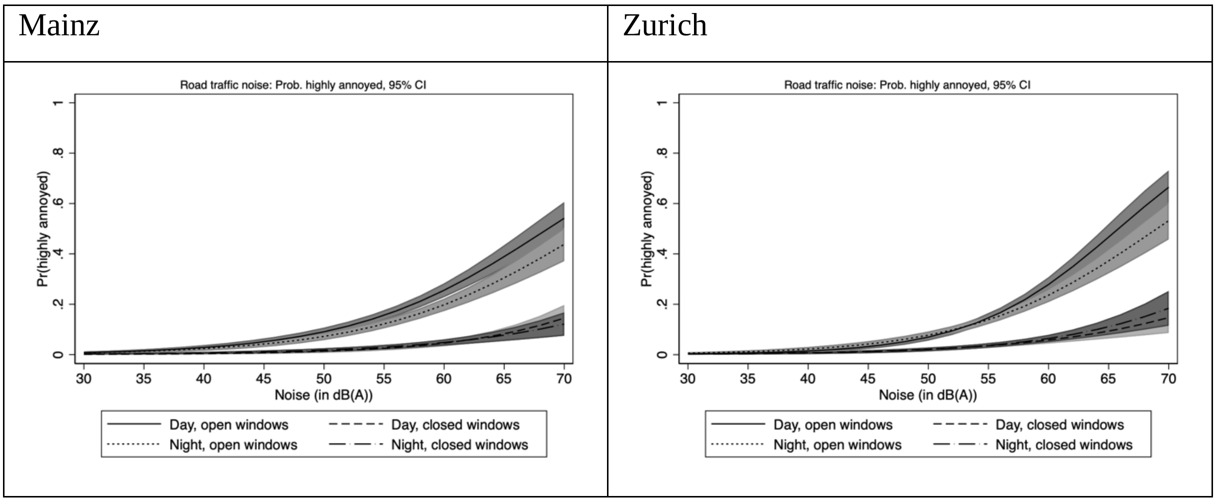

Fig. 1. Exposure-response curves for road traffic noise.

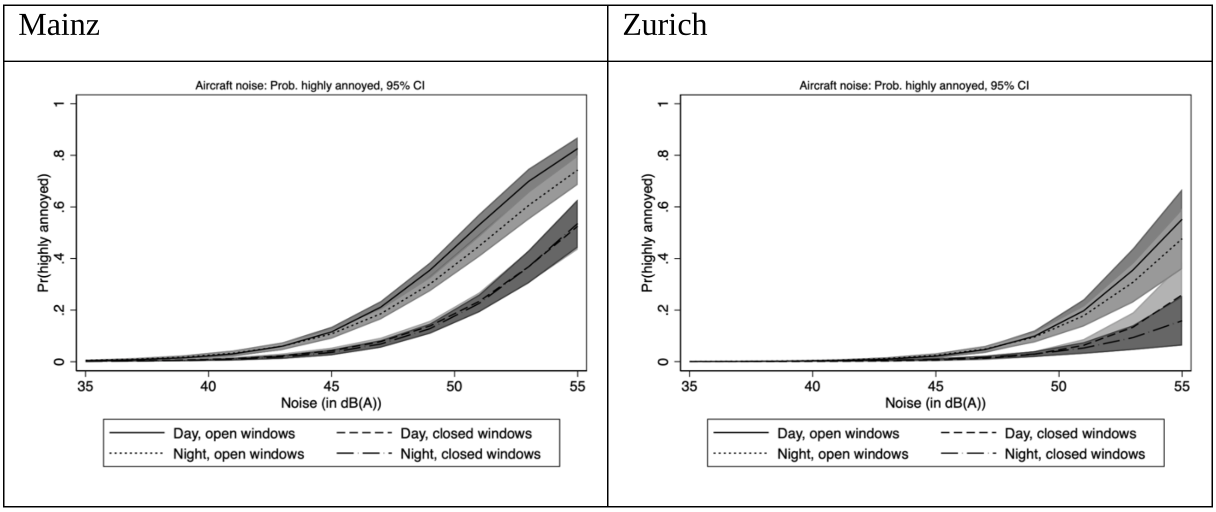

Fig. 2. Exposure-response curves for aircraft noise.

Like the %HA values in Table 1, the exposure-response curves for road traffic noise are similar in Mainz and Zurich. However, we can observe a certain tendency for respondents in Mainz to react to high road traffic noise (65 dB+) less sensitively, i.e. to articulate feelings of annoyance less often. For aircraft noise, on the other hand, the curves are quite different in the two cities. Even if we take into account the limited comparability of our aircraft Lden measures (Footnote 1 above), we feel safe in saying that the dose-response curves in Mainz run on a higher level than those in Zurich. Based on the stronger public salience of aircraft noise in Mainz, we expected this result for aircraft noise. It also seems plausible that this salience of aircraft noise simultaneously contributes to a slightly reduced annoyance due to road traffic noise in Mainz. Finally, Figures 1 and 2 confirm the robust finding of noise research that a given level of noise exposure (e.g. Lden = 50 dB in the two figures) induces more annoyance in the case of aircraft than in the case of road traffic noise.

Table 2 displays the descriptive statistics of the independent variables, which will be included in our multivariate models on noise annoyance (in Section 4). 62 percent of the respondents answer that they are living in a dwelling with high-quality windows (codes 4-5 of our item measuring window quality). Environmental concern has a mean of 3.5 on our 1-5 environmental concern scale. The income variable has more missing values than the other variables, and this contributes to a substantial reduction of the number of cases in the multivariate models to n = 2,611. The average income, adjusted for purchasing power parity, is 2,996 Euros.

Table 2

Set of independent variables.

Independent variables	Obs.	Mean	Std. Dev.	Min.	Max.
Road traffic noise Lden in dB(A)	2,611	52.91	7.73	32.17	77.50
Aircraft noise Lden in dB(A)	2,611	45.24	3.80	35.16	55.66
Window quality	2,611	3.70	1.07	1	5
Environmental concern	2,611	3.50	0.77	1	5
Income (divided by 1,000)	2,611	3.00	1.52	0.20	10.00
Dwelling size in m^2 (divided by 10)	2,611	9.32	4.27	1	30
Sleeping room faces street	2,611	0.52	0.50	0	1
Dwelling with outdoor garden	2,611	0.41	0.49	0	1
Female	2,611	0.53	0.50	0	1
Age in years (divided by 10)	2,611	4.20	1.37	1.80	7.00
Age squared	2,611	19.54	12.21	3.24	49.00
Education in years	2,611	15.25	2.72	8	18
Labor force participation	2,611	0.73	0.44	0	1
Owner of dwelling	2,611	0.23	0.42	0	1
Years living in dwelling (ln)	2,611	2.00	0.85	0	4.19
Noise sensitivity	2,611	3.19	0.87	1	5
Own car use	2,611	0.70	0.46	0	1
Own air flights last year	2,611	0.71	0.45	0	1
Mainz	2,611	0.45	0.50	0	1

As a preliminary to the multivariate analyses, we calculated – with respect to our three main topics – bivariate tables, which look at the %HA for respondents (1) living in a dwelling with low-quality versus high-quality windows, (2) having low versus high environmental concern, and (3) endowed with low versus high income. These tables are shown and interpreted in Appendix S3.

4. Multivariate results

For the multivariate models, we do not use binary logistic regression models with %HA as dependent variable, but OLS regression models with the 11-point annoyance scale as dependent variable. Although OLS regressions do not fit exactly because the dependent variables are not normally distributed, OLS models have the advantage that they exploit the data of the 11-point scale more fully than 0/1 logistic regressions. Nevertheless, as a robustness check, we re-run our OLS regressions also as binary logistic regressions (Appendices S4 and S5) and can report that the results are similar, with the general tendency that the effects of the covariates are more clear-cut for the OLS than for the logistic regressions. Table 3 presents the results of the regression models for annoyance due to road traffic, and Table 4 the results for annoyance due to aircraft noise.

Table 3

Factors affecting annoyance due to road traffic noise (OLS regressions).

Independent variables	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Road traffic noise Lden in dB(A)	0.17*** (25.72)	0.09*** (17.41)	0.15*** (21.19)	0.08*** (15.11)
Window quality	-0.37*** (7.51)	-0.64*** (17.31)	-0.37*** (7.27)	-0.50*** (13.66)
Environmental concern	0.35*** (5.06)	0.11* (2.15)	0.30*** (4.20)	0.10 (1.96)
Income (divided by 1,000)	-0.07 (1.60)	-0.06* (2.04)	-0.02 (0.56)	-0.03 (0.79)
Dwelling size in m^2 (divided by 10)	-0.01 (0.99)	0.01 (1.01)	0.00 (0.03)	0.00 (0.17)
Sleeping room faces street	0.86*** (8.21)	0.56*** (7.18)	1.31*** (12.03)	0.71*** (9.02)
Dwelling with outdoor garden	-0.40*** (3.49)	-0.15 (1.79)	-0.38** (3.17)	-0.15 (1.79)
Female	-0.06 (0.62)	-0.12 (1.57)	-0.12 (1.15)	-0.13 (1.71)
Age in years (divided by 10)	0.23 (0.77)	-0.02 (0.10)	0.49 (1.59)	0.08 (0.38)
Age squared	-0.03 (0.81)	0.00 (0.09)	-0.06 (1.60)	-0.01 (0.43)
Education in years	-0.01 (0.24)	-0.01 (0.53)	0.01 (0.33)	-0.00 (0.22)
Labor force participation	-0.13 (0.91)	0.07 (0.68)	-0.02 (0.13)	0.16 (1.51)

Owner of dwelling	0.08	-0.02	0.11	0.04
	(0.50)	(0.21)	(0.66)	(0.35)
Years living in dwelling (ln)	0.06	0.01	0.06	0.04
	(0.76)	(0.24)	(0.77)	(0.69)
Noise sensitivity	0.56***	0.36***	0.68***	0.42***
	(9.46)	(8.13)	(10.85)	(9.37)
Own car use	-0.01	-0.15	-0.20	-0.12
	(0.11)	(1.59)	(1.57)	(1.31)
Mainz	-0.12	-0.16	-0.33*	-0.21*
	(0.95)	(1.71)	(2.57)	(2.25)
Constant	-7.34***	-2.04***	-8.10***	-2.88***
	(9.18)	(3.42)	(9.69)	(4.80)
Adj. R^2	0.31	0.27	0.29	0.23
No. of cases	2,611	2,611	2,611	2,611

Notes: Unstandardized regression coefficients with absolute t-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Focusing on the effects of noise exposure, window quality, environmental concern, and income, Table 3 shows the following results. As expected, road traffic noise exposure has very strong positive effects on noise annoyance in the four different constellations (day/open windows, day/closed windows, etc.). Gauging by the t-values of the unstandardized regression coefficients (or, alternatively, the size of the standardized regression coefficients in Appendices S6 and S7), noise exposure is the most important influence factor on noise annoyance. Both during the day and during the night, the exposure effect is stronger when the windows are open, compared to when they are closed. This seems plausible because the correspondence between outdoor and indoor noise is certainly higher when the windows are open than when they are closed.

In accordance with our expectations, the variable “quality of the windows” yields highly significant negative effects on noise annoyance due to road traffic. Not surprisingly, the window quality effects are more pronounced in the closed windows constellations. Nevertheless, high-quality windows contribute to a reduction of noise annoyance also in the open windows constellations. This suggests that, in addition to a direct noise reduction effect, high-quality windows have an indirect effect on annoyance by enhancing a respondent’s perceived noise control. Respondents whose dwellings are equipped with high-quality windows know that they can actively control the indoor noise situation by closing their windows, and this knowledge presumably reduces negative feelings of annoyance when road traffic noise intrudes into the dwelling through open windows.[2]

Concerning the effects of general environmental attitudes, Table 3 shows that respondents with higher environmental concern articulate annoyance from road traffic noise more often. Since the models also control for noise sensitivity, the environmental concern effects cannot be explained by a stronger noise sensitivity of environmentally concerned people (as suggested, for instance, by Miedema, 2007: 51 and Okokon et al., 2015). Environmental concern and noise sensitivity correlate in our data only moderately with $r = 0.16$ ($p<0.001$). As far as we know, no prior study has reported these relatively strong environmental concern effects. The effects seem to be stronger when windows are open than when they are closed. We might speculate that the situation of open windows, which induces much more respondents to articulate feelings of annoyance, leaves more room for subjective interpretations and thus for the influence of attitudinal factors.

For income, we observe negative effects on noise annoyance from road traffic in all four regressions. However, the income coefficient is significant only in the case when windows are closed during the day. While the direct income effects in Table 3 are rather weak, there are indirect pathways (i.e. mediator variables) between household resources and the degree of noise annoyance from road traffic. These indirect pathways are summarized in Appendix S8. First of all, income affects the choice of the place of residence and there is a significant negative income effect on road traffic noise exposure. Moreover, respondents with higher income are more often protected by high-quality windows than respondents with lower income; they are less likely to have their sleeping room facing the street; and they are more likely to have an outdoor garden. Given the effects of noise exposure, window quality, sleeping room location and outdoor garden in Table 3, these four indirect pathways reduce the annoyance of wealthier respondents. However, there is one pathway that goes in the opposite direction: high-income respondents are more noise sensitive than low-income respondents are. Supplementary regression models (shown in Appendix S9), which exclude the mediator variables and thus inform about the total (i.e. direct and indirect) income effects, yield the

[2] An alternative explanation for the “quality of windows effect” even with open windows could be a reverse causality due to our potentially biased subjective measurement of window quality. It may be that those who are more annoyed by noise in their dwelling tend to assess their window quality to be lower. However, given the strength of the effects, this would imply a very strong bias of our subjectively measured window quality variable.

final result that the total income effects on road traffic noise annoyance are clearly negative and at least twice as strong as the simple direct effects in Table 3.

It seems worthwhile to comment briefly on the other covariates in Table 3. Contrary to our prediction, the size of the dwelling does not yield a negative effect on road traffic noise annoyance; none of the four regression coefficients is significant. When their sleeping room has one or more windows facing the street, respondents feel significantly more often annoyed by road noise. To have an outdoor garden reduces indoor annoyance, particularly in the open windows constellations. An explanation may be that open windows showing to a quiet backyard garden (possibly with trees and birds) stimulate subjective well-being and reduce, if present, the relative salience of front door traffic noise. Gender, age, education, labor force participation, ownership of dwelling, and years of living in the dwelling do not show significant effects. Based on prior studies, we expected inverted u-shaped effects for age and negative effects of labor force participation, because respondents who are active in the labor force usually stay fewer hours at home. In line with previous research, noise sensitivity strongly increases feelings of annoyance caused by road traffic. The effects of our covariates "own car use" and "city (1 = Mainz)" do not consistently differ from zero, even though there is a tendency of less annoyance from road traffic in Mainz during the night.

Turning to Table 4, we also see for aircraft noise that the exposure level is the most powerful single predictor of the corresponding annoyance. As in the case of road traffic noise, the exposure effects are more pronounced for the open than for the closed windows constellations. Furthermore, in accordance with previous studies, the Lden effects of aircraft noise are stronger than the Lden effects of road traffic noise. This means that the same level of noise exposure induces more annoyance in the case of aircraft than in the case of road traffic noise. The stronger effects of aircraft noise exposure are one of the reasons why the fit values (adjusted R^2) of the models for aircraft noise annoyance are higher than the fit values of the models for road traffic noise annoyance.

The pattern of the effects of the variable "window quality" is also parallel to the pattern that we observed for road traffic noise annoyance. High-quality windows clearly reduce noise annoyance due to aircraft noise for both the open and the closed windows constellation, but more clearly when the windows are closed. The data also show that the "protection effect" of high-quality windows is weaker for aircraft than for road traffic noise.

Table 4 yields four highly significant effects of environmental concern on aircraft noise annoyance. Again, the path over noise sensitivity cannot explain these effects because the models control for noise sensitivity. An explanation may be that environmentally concerned people articulate more annoyance because of a higher political attention and a stronger likelihood of speaking up against environmental risks. As in the case of road traffic noise, the environmental concern effects tend to be stronger for the open than for the closed windows constellations. Contrary to our expectation, the environmental concern effects are not consistently more pronounced for aircraft than for road traffic annoyance. This means that we do not find support for the hypothesis that "environmentalists" (i.e. respondents with high environmental concern) react to aircraft noise with more anger than to road traffic noise.

As before with the road traffic estimations, we distinguish between direct and indirect income effects. In Table 4, we observe a direct relation between income and aircraft annoyance that is positive and significant in three of the four situations. In addition, Appendix S8 shows that the direct income relation is enhanced by indirect pathways via the following mediators: dwelling size, outdoor garden, homeownership, and noise sensitivity. These four variables are positively affected by income (Appendix S8) and – as we will comment on below – positively affect aircraft noise annoyance (Table 4). Two counteracting factors diminish the overall relation of income and aircraft noise: high-income households are objectively less exposed to aircraft noise (Appendix S8) and, as we know, are more often protected by high-quality windows. The finding that financially privileged people feel stronger annoyed by aircraft noise, although they are (holding other influence factors constant) less exposed to noise from airplanes, is remarkable. The two counteracting factors do not fully compensate for the positive direct and indirect associations of income and annoyance due to aircraft noise. Supplementary regressions (shown in Appendix S10), which exclude the mediator variables, lead to the conclusion that the total income effects on aircraft noise annoyance are positive. The strength of these total effects roughly corresponds the strength of the direct income effects in Table 4.

Table 4

Factors affecting annoyance due to aircraft noise (OLS regressions).

Independent variables	Day, windows open	Day, windows closed	Night, windows open	Night, windows closed
Aircraft noise Lden in dB(A)	0.40*** (31.46)	0.27*** (25.56)	0.33*** (24.29)	0.24*** (22.00)
Window quality	-0.26*** (5.72)	-0.42*** (11.18)	-0.25*** (5.31)	-0.34*** (8.89)
Environmental concern	0.34*** (5.46)	0.20*** (3.91)	0.32*** (4.78)	0.20*** (3.80)
Income (divided by 1,000)	0.06 (1.65)	0.08* (2.47)	0.09* (2.25)	0.08* (2.45)
Dwelling size in m^2 (divided by 10)	0.03* (2.56)	0.03** (3.04)	0.04** (2.92)	0.04*** (3.67)
Sleeping room faces street	-0.23* (2.43)	-0.10 (1.28)	-0.12 (1.23)	-0.07 (0.93)
Dwelling with outdoor garden	0.49*** (4.72)	0.41*** (4.70)	0.44*** (3.97)	0.44*** (5.00)
Female	-0.09 (0.97)	-0.00 (0.06)	-0.03 (0.29)	0.04 (0.47)
Age in years (divided by 10)	1.17*** (4.38)	0.94*** (4.24)	1.69*** (5.89)	1.20*** (5.28)
Age squared	-0.08** (2.74)	-0.07** (2.83)	-0.14*** (4.30)	-0.10*** (3.89)
Education in years	0.01 (0.34)	-0.01 (0.65)	0.02 (0.75)	0.01 (0.37)
Labor force participation	0.04 (0.33)	0.05 (0.49)	-0.06 (0.43)	-0.03 (0.29)
Owner of dwelling	0.38** (2.63)	0.21 (1.77)	0.56*** (3.63)	0.29* (2.34)
Years living in dwelling (ln)	0.02 (0.29)	0.03 (0.49)	-0.06 (0.83)	-0.04 (0.70)
Noise sensitivity	0.47*** (8.77)	0.29*** (6.48)	0.43*** (7.35)	0.29*** (6.32)
Own air flights last year	-0.15 (1.42)	-0.12 (1.31)	-0.07 (0.65)	-0.06 (0.64)
Mainz	1.56*** (13.90)	0.91*** (9.78)	1.29*** (10.70)	0.79*** (8.31)
Constant	-21.70*** (24.16)	-14.39*** (19.25)	-20.39*** (21.14)	-14.20*** (18.58)
Adj. R^2	0.46	0.37	0.36	0.31
No. of cases	2,611	2,611	2,611	2,611

Notes: Unstandardized regression coefficients with absolute t-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Looking at the remaining covariates in Table 4, there are similarities but also remarkable differences with the findings for road traffic. The similarities relate to gender, education, labor force participation, years of living in the dwelling, and own air flights taken in the last year (replacing "own car use" in Table 3), which do not have significant effects. Noise sensitivity, on the other hand, again turns out to be highly significant.

The differences are as follows. Whereas the dwelling size was not significant in the case of road traffic noise annoyance (we expected a negative effect), it is significantly positive in the case of aircraft noise annoyance. We might conjecture that respondents with bigger dwellings are especially annoyed by aircraft noise because this type of noise (in contrast to road traffic noise) usually affects all rooms of the dwelling and thus there is no opportunity to avoid noise by changing to quieter rooms in the dwelling. The variable "sleeping room faces street" yielded strong positive effects on road traffic noise annoyance but shows no or rather negative effects on aircraft noise annoyance. Again, the encompassing nature of aircraft noise can probably explain this finding. A complete reversal of the effects can be seen for the "outdoor garden" variable. This reduces annoyance from road traffic, but increases annoyance from aircraft noise. When aircraft noise is present, it also affects the back garden and, because a garden usually serves as a place to relax, noise seems to be especially annoying there. Different from the case of road traffic noise, ownership of a dwelling significantly increases annoyance due to aircraft noise. This finding can be seen as a confirmation of Fischel's (2001) so-called homevoter hypothesis. Fischel argues that homeowners – guided by their concern about the real-estate value of their private property – exhibit "hypersensitivity to local environmental risk" (p. 205) and thus oppose all circumstances and events that have the potential to endanger their property asset. Empirical tests of the Fischel hypothesis (e.g. Dehring et al., 2008; Preisendörfer, 2021) usually distinguish between a consumption and a wealth effect of local environmental goods or bads. The consumption effect denotes the direct utility of environmental goods in terms of quality of life. The wealth effect encompasses the monetary effects of (changing) environmental conditions in terms of capitalization. A decline in environmental conditions will have a negative consumption effect for both renters and homeowners, but the wealth effect tends to be positive for renters manifesting in lower rents and negative for homeowners due to lower housing prices and/or less rent revenue. Thus, consumption and wealth effects function for renters in opposite directions (compensation mechanism), while they are unidirectional for homeowners – providing a core argument for their hypersensitivity to environmental bads. Our finding that aircraft noise significantly increases homeowners' annoyance, while road traffic noise does not, indicates that homeowners see aircraft noise as more of a danger to their self-interest than road traffic noise. Finally, Table 4 clearly validates our prediction that the Mainz respondents react to aircraft noise with stronger annoyance than the Zurich respondents do. This supports the assumption that a local context with greater salience and public attention to a noise source increases feelings of annoyance due to this source.[3]

5. Discussion and conclusions

The presented results confirm our predictions on the role of windows and the role of environmental concern regarding noise annoyance. Closed windows in general and closed high-quality windows in particular unfold their effects along two paths: first, they directly prevent the intrusion of outdoor noise into the dwelling, and thus reduce indoor noise and noise annoyance; and second, they provide an opportunity to cope with noise and to control the noise situation, and this reduces annoyance even in constellations when exposure to noise is actually given (i.e. when the windows of the dwelling are open). Environmental concern, too, is an important factor. Environmentally concerned people articulate annoyance from road traffic and aircraft noise significantly more often, also under control of other influence factors (including noise exposure and noise sensitivity). Environmental concern seems to be aligned with a special alertness and a critical attitude toward noise as an environmental risk, and this evidently stimulates noise annoyance. The influences of income on annoyance are less clear-cut and obviously more complex. Here we have to disentangle direct and several indirect effects. All in all, we found a negative overall association of income with road traffic noise annoyance. The overall association of income with aircraft noise annoyance was positive, although high-income people were less exposed to noise from airplanes. Only the negative association is in line with expectations from environmental inequality research.

In addition to these results, pertaining to the main topics of this article, a couple of further findings deserve attention (e.g. the finding that several influence factors affect road traffic and aircraft noise annoyance quite differently; or the finding regarding the pronounced urban context-effects on aircraft noise annoyance), but we will not reiterate them here.

Our findings on the role of windows have the practical implication that investments in high-quality windows can be seen as an effective noise mitigation measure – “effective” in the

[3] Appendix S11 augments our regression models in Table 3 and 4 by additional robustness analyses, which focus on the effects of our three main independent variables (window quality, environmental concern, and income).

sense that such investments reduce people’s subjective feelings of annoyance due to indoor noise at home. Nevertheless, high-quality windows and other devices of noise insulation of buildings remain “second-best” solutions. Noise avoidance measures at the source are usually the most preferable option (e.g. Klæboe et al., 2011). To abstain from opening the windows because it is noisy outside restricts individual freedom and impairs the subjective well-being and quality of life. Closed windows are often only a partial protection against noise, particularly aircraft noise. People both with and without high-quality windows are often outside their home, and in a noisy neighborhood all residents are affected by this outdoor noise. Finally, road traffic and aircraft noise are often directly connected with other environmental risks, especially air pollution, and windows tend to offer less protection against these risks.

The positive effects of environmental concern on noise annoyance may mean – based on the assumption of environmental quality as a “luxury good” (e.g. Martínez-Alier, 1995) – that the populations of more affluent societies generally develop a higher noise aversion, showing more negative feelings and stronger opposition against residential noise. If this holds true, this is important for future projects in the area of urban planning, changes of infrastructure, and related public or private activities (housing projects, industrial siting, etc.). The avoidance of noise and noise annoyance would gain greater political priority.

Noise reduction measures should target poorer households in densely populated urban areas that are exposed to high levels of noise. While affluent households can afford to move to less noisy places of residence or shield themselves against outdoor noise, low-income households often do not have these opportunities. Subsidizing high-quality windows for socially disadvantaged households could be one way to diminish noise annoyance and inequality in exposure to noise emissions. Once more, however, the reduction of noise emissions at the origin in noisy urban neighborhoods is most important.

Like other studies, ours has weaknesses and limitations. Our survey pertains to two cities and thus has a local restriction. The selection of Mainz and Zurich was mainly motivated by the fact that both cities are confronted with above-average levels of aircraft noise. The city context concerning road traffic noise did not influence our decision to choose those two cities. Of course, it would be preferable to investigate additional cities, including cities with less urgent problems in the area of noise on the one hand and more urgent problems on the other. Our measure of window quality rested on subjective assessments of the survey participants. More professional, expert ratings of window quality would clearly strengthen our arguments regarding the shielding power of windows. In addition to the windows, it would be useful to know other characteristics of the buildings (e.g. whether they have façade insulation) and the dwellings (e.g. the internal arrangement of the rooms). The relationship between outdoor noise and subjective noise annoyance in the dwelling is mediated by the indoor noise level, which certainly differs from the outdoor noise level in the case of keeping the windows closed. To know this level of indoor noise (in different rooms of the dwelling) could improve our understanding of noise annoyance at home (Amundsen et al., 2011, 2013), but we did not have data on indoor noise exposure. With respect to environmental concern, too, the mechanisms responsible for the observed effects on annoyance deserve more detailed research. Contrary to the findings of other studies (Okokon et al., 2015), we did not find that environmental considerations indirectly affect annoyance by influencing noise sensitivity. Our analyses did not yield such an indirect effect, but a direct effect of environmental concern on annoyance independent of noise sensitivity. We tried to explain this direct effect by a "political alertness mechanism." Environmentally concerned individuals articulate noise annoyance more often because they have a special political mindset that makes them more attentive and more alert against environmental risks. We think it would be a worthwhile research topic to investigate whether such a politically framed mindset exists and interferes with individual well-being. In addition, more in-depth analyses looking at the role of income and socioeconomic resources are needed.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Online supplementary material to the article

"Annoyance due to residential road traffic and aircraft noise: Empirical evidence from two European cities"

Appendix S1

Administrative data on road traffic and aircraft noise.

Mainz road traffic noise data: For big cities such as Mainz, the Environmental Noise Directive of the European Union 2002/49/EC mandates the publication of strategic maps of road traffic noise (European Commission, 2002). According to this directive, noise is modelled at the noisiest façade of every building at 4 meters above ground and made available as a raster map on a 10-meter grid. Such data for the year 2012 was provided to us by the Grün- und Umweltamt Mainz (2017). No new maps for road traffic noise have been created up to the time of our study, as changes since 2012 have been deemed minor. For the purpose of our analyses, the original Lden values in categories of 5 dB(A) (i.e. <35, 35-39.9, 40-44.9, 45-49.9 … 75-79.9) are replaced by category midpoints assuming a lower bound of 30 dB(A) for the first interval. This results in values of 32.5, 37.5, 42.5 … 77.5 dB(A).

Zurich road traffic noise data: The road traffic noise data for 2015 came from the National Noise Monitoring Database sonBASE (Swiss Federal Office for the Environment, 2018). In sonBASE, noise is modelled at multiple façade points on every floor of a building. We received noise values for all façade points of the buildings on our address list. However, in some cases, the addresses did not correspond to buildings, for which noise was modelled, but had been matched to nearby different buildings, to a group of adjacent buildings or to buildings that had been demolished and replaced in the meantime. In order to reduce the impact of these issues, only façade points both within a radius of 20 meter from our respondents' coordinates and on the same building floor as the respondents' apartments were considered relevant. For this purpose, the respondents' floors were adopted from the Federal Register of Buildings and Dwellings (Swiss Federal Statistical Office, 2017). If no façade points on the given floor were found, a nearby floor was assigned (at a maximum distance of ±2.5 floors from the original floor). All cases without any points within the 20-meter radius were inspected visually using QGIS. This revealed that for twenty buildings, the reason for the points being at a greater distance was the building geometry (typically a very large building). In these cases, all of the buildings' façade points on the relevant floor were considered meaningful. Lden values were computed based on A-weighted long-term average sound levels for daytime (7:00-19:00), evening (19:00-23:00) and nighttime (23:00-7:00), applying the usual penalties for evening and nighttime noise of 5 dB and 10 dB, respectively (see Brink et al., 2018).

Mainz aircraft noise data: Aircraft noise data for the year 2016 was provided to us by the environmental center "Gemeinnützige Umwelthaus GmbH" that is responsible to map and monitor aircraft noise in the Frankfurt Rhine-Main Metropolitan Area on behalf of the state of Hessen. Noise is modelled based on the six busiest months of the year 2016. While the spatial data was not made available in full, A-weighted long-term average sound levels for daytime (6:00-22:00) and nighttime (22:00-6:00) were provided for every address in the sample. Based on this, we calculated approximate Lden values following the suggestions of Brink et al. (2018).

Zurich aircraft noise data: The Flughafen Zurich AG (2017) provided these data as raster map for the year 2017 at a 150-meter resolution. Noise values were available for daytime (6:00-22:00) as well as the first (22:00-23:00) and second hour of nighttime (23.00-00.00). These values are modelled in accordance with the Swiss noise abatement ordinance (Swiss Federal Council, 1986). Noise by large aircrafts was based on traffic data for the year 2016 and includes all charter and scheduled flights. However, for small aircrafts (maximum weight of less than 8,618 kg at take-off), noise is based on the two busiest days of the year 2010 and modelled with a small penalty. Again, we followed the suggestions of Brink et al. (2018) to calculate approximate Lden values.

References for Appendix S1

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Appendix S2

Measurement of environmental concern and noise sensitivity.

Environmental concern: Question wording: "Using a scale from 1 (strongly disagree) to 5 (strongly agree), what is your position with respect to the following statements? (1) I am afraid when I think about the future environmental conditions for our children and grandchildren. (2) If we continue our current lifestyle, we run the risk of an environmental catastrophe. (3) The majority of people do not act in an environmentally responsible way. (4) In my opinion, environmental problems are greatly exaggerated by proponents of the environmental movement. (5) It is still true that politicians are doing far too little to protect the environment. (6) To protect the environment, we should be willing to constrain our current standard of living." An additive index of environmental concern was constructed with a range from 1 to 5 (item 4 reversed, sum of the six items, divided by six). A principal components analysis shows that the environmental concern items load on a single factor (eigenvalue = 3.00; explained variance = 50%; all factor loadings > 0.70). Cronbach's alpha for the environmental concern scale is 0.80.

Noise sensitivity: Question wording: "Please answer on a scale from 1 (strongly disagree) to 5 (strongly agree) whether you agree with the following statements: (1) I get annoyed when my neighbors are noisy. (2) I get used to most noises without much difficulty. (3) I find it hard to relax in a place that's noisy. (4) I get mad at people who make noise that keeps me from falling asleep or getting work done. (5) I am sensitive to noise." An additive index of noise sensitivity was constructed with a range from 1 to 5 (item 2 reversed, sum of the five items, divided by five). A principal components analysis shows that the noise sensitivity items load on a single factor (eigenvalue = 2.67; explained variance = 53%; all factor loadings > 0.50). Cronbach's alpha for the noise sensitivity scale is 0.78.

Appendix S3

Bivariate relationships between those highly annoyed by road traffic and aircraft noise (%HA) on the one hand and window quality, environmental concern and income on the other hand.

With respect to our research topic "window quality," Table S3.1 presents the %HA for those living in a dwelling with low-quality windows (codes 1-3 of our item measuring window quality, 38 percent of the respondents) and those with high-quality windows (codes 4-5, 62 percent).

Table S3.1

Percent highly annoyed due to road traffic and aircraft noise in Mainz and Zurich in four different constellations and for two levels of the window quality of the dwelling.

	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Road traffic noise in Mainz				
Low-quality windows	21.1	6.1	15.5	6.3
High-quality windows	13.3 *	1.1 *	11.5 *	1.2 *
Road traffic noise in Zurich				
Low-quality windows	23.9	8.9	21.7	9.0
High-quality windows	12.0 *	1.2 *	10.8 *	1.5 *
Aircraft noise in Mainz				
Low-quality windows	27.1	14.7	24.8	13.7
High-quality windows	22.7 *	7.2 *	18.8 *	6.8 *
Aircraft noise in Zurich				
Low-quality windows	5.1	2.5	4.8	2.6
High-quality windows	4.1	1.0 *	4.1	0.8 *

Notes: * significant at 5 percent level (chi-square tests).

For 14 of 16 related %HA pairs in Table S3.1, respondents living in a dwelling with high-quality windows have significantly lower %HA values than those with low-quality windows. The percentage point differences are more pronounced for %HA pairs pertaining to road traffic than to aircraft noise annoyance. This confirms the conjecture that high-quality windows are a more effective shielding device against road traffic than against aircraft noise. When high-quality windows are closed, only 1 percent of the respondents articulate annoyance due to road traffic noise. For aircraft noise, the highest %HA value in the constellation of closed windows is 7 percent, in Mainz during the day as well as during the night.

Looking at the %HA when the windows are open (both in the day and in the night) yields the observation that, already in this constellation, the %HA are lower for high-quality as compared to low-quality windows. At first glance, this might seem curious. However, because Table S3.1 reports only bivariate findings, we have to be aware that other factors may be responsible for these differences – factors we will try to control for in our multivariate models.

With respect to our second research topic, the role of environmental concern for noise annoyance, Table S3.2 differentiates the %HA values for respondents with low and high environmental concern. We used a median split to transform our continuous environmental concern index (with a range from 1 to 5) into a low and a high concern group.

Table S3.2

Percent highly annoyed due to road traffic and aircraft noise in Mainz and Zurich in four different constellations and for two levels of a respondent's environmental concern.

	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Road traffic noise in Mainz				
Low environmental concern	12.8	2.4	10.2	2.3
High environmental concern	20.9 *	4.2	16.6 *	4.7 *
Road traffic noise in Zurich				
Low environmental concern	14.3	3.7	12.3	3.3
High environmental concern	17.6 *	3.8	16.7 *	4.8
Aircraft noise in Mainz				
Low environmental concern	20.9	8.4	17.6	7.2
High environmental concern	28.8 *	12.8 *	25.9 *	12.8 *
Aircraft noise in Zurich				
Low environmental concern	4.5	1.4	3.7	1.2
High environmental concern	4.4	1.6	5.0	1.7

Notes: * significant at 5 percent level (chi-square tests).

In line with our expectation, respondents with high environmental concern articulate annoyance due to road traffic and aircraft noise more often than respondents with low environmental concern. For 9 of 16 %HA pairs in Table S3.2, percentage point differences are significant at the 5 percent level in the predicted direction. Since the %HA values for aircraft noise in Zurich are generally very low, it comes as no surprise that the corresponding differences depending on environmental concern are rather small.

With respect to our third research topic, the role of income, the %HA for households with low versus high income are depicted in Table S3.3. The low-income and high-income groups were fixed by a median split of the income variable.

Table S3.3

Percent highly annoyed due to road traffic and aircraft noise in Mainz and Zurich in four different constellations and for two levels of income.

	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Road traffic noise in Mainz				
Low household income	18.7	3.9	15.6	3.9
High household income	14.1 *	2.4	10.3 *	2.7
Road traffic noise in Zurich				
Low household income	17.4	5.2	14.7	4.3
High household income	15.0	3.1*	14.1	3.7
Aircraft noise in Mainz				
Low household income	22.7	8.1	18.3	7.6
High household income	26.9	13.3 *	25.2 *	12.5 *
Aircraft noise in Zurich				
Low household income	1.7	5.1	2.3	5.5
High household income	1.1	4.1	0.8	3.9

Notes: * significant at 5 percent level (chi-square tests).

There is a complex pattern of correlations between income and noise annoyance. In Mainz, road traffic noise is a larger subjective burden for low-income than for high-income households. Interestingly, for aircraft noise, this relation is reversed. Richer households complain more about aircraft noise than poorer households do. In Zurich, we observe smaller negative correlations between income and annoyance due to road traffic noise, and although the correlations between income and aircraft noise annoyance also tend to be negative, the differences are not significant.

Appendix S4

Factors affecting annoyance due to road traffic noise (binary logit models).

Independent variables	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Road traffic noise Lden in dB(A)	0.14***	0.09***	0.13***	0.09***
	(15.83)	(5.82)	(13.50)	(5.67)
Window quality	-0.26***	-0.78***	-0.19**	-0.66***
	(4.71)	(7.61)	(3.29)	(6.72)
Environmental concern	0.32***	-0.06	0.29**	0.33*
	(3.77)	(0.36)	(3.28)	(2.14)
Income (divided by 1,000)	-0.07	-0.12	0.02	-0.01
	(1.43)	(1.08)	(0.36)	(0.01)
Dwelling size in m^2 (divided by 10)	-0.03	0.03	-0.01	-0.01
	(1.44)	(0.89)	(0.54)	(0.39)
Sleeping room faces street	0.70***	1.53***	1.08***	1.25***
	(5.37)	(4.55)	(7.49)	(4.19)
Dwelling with outdoor garden	-0.19	-0.45	-0.26	-0.42
	(1.29)	(1.48)	(1.71)	(1.45)
Female	-0.12	-0.09	-0.08	-0.29
	(0.95)	(0.39)	(0.60)	(1.22)
Age in years (divided by 10)	0.18	-0.62	0.59	0.17
	(0.50)	(0.94)	(1.55)	(0.24)
Age squared	-0.01	0.08	-0.07	-0.02
	(0.36)	(1.04)	(1.58)	(0.24)
Education in years	0.01	-0.06	0.01	-0.01
	(0.49)	(1.33)	(0.30)	(0.22)
Labor force participation	-0.13	0.68*	-0.32	0.49
	(0.78)	(2.11)	(1.86)	(1.52)
Owner of dwelling	0.26	-0.34	0.19	-0.14
	(1.28)	(0.69)	(0.89)	(0.32)
Years living in dwelling (ln)	-0.13	-0.10	0.11	0.16
	(1.39)	(0.51)	(1.14)	(0.84)
Noise sensitivity	0.47***	0.56***	0.74***	0.61***
	(6.42)	(4.00)	(9.17)	(4.35)
Own car use	0.15	-0.40	-0.33*	-0.44
	(1.08)	(1.52)	(2.24)	(1.72)
Mainz	-0.37*	-0.37	-0.31	-0.35
	(2.43)	(1.28)	(1.92)	(1.22)
Constant	-11.53***	-6.42***	-13.16***	-10.24***
	(11.01)	(3.46)	(11.54)	(5.30)
McFadden R^2	0.22	0.26	0.23	0.23
No. of cases	2,611	2,611	2,611	2,611

Notes: Unstandardized logit coefficients with absolute z-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix S5

Factors affecting annoyance due to aircraft noise (binary logit models).

Independent variables	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Aircraft noise Lden in dB(A)	0.40^{***}	0.37^{***}	0.37^{***}	0.35^{***}
	(16.79)	(10.59)	(15.49)	(9.88)
Window quality	-0.22^{**}	-0.75^{***}	-0.28^{***}	-0.72^{***}
	(2.98)	(6.78)	(3.66)	(6.51)
Environmental concern	0.42^{***}	0.20	0.45^{***}	0.37^{*}
	(3.86)	(1.30)	(4.08)	(2.33)
Income (divided by 1,000)	0.04	0.20^{*}	0.09	0.09
	(0.64)	(2.13)	(1.28)	(0.93)
Dwelling size in m^2 (divided by 10)	0.02	0.04	0.02	0.06^{*}
	(1.19)	(1.44)	(1.21)	(2.06)
Sleeping room faces street	-0.22	0.07	-0.25	-0.08
	(1.46)	(0.30)	(1.59)	(0.37)
Dwelling with outdoor garden	0.39^{*}	0.44	0.24	0.65^{*}
	(2.27)	(1.68)	(1.37)	(2.40)
Female	0.01	-0.06	0.07	-0.13
	(0.09)	(0.26)	(0.42)	(0.55)
Age in years (divided by 10)	1.28^{**}	2.15^{**}	2.28^{***}	1.73^{*}
	(2.92)	(3.13)	(4.70)	(2.40)
Age squared	-0.09	-0.18^{*}	-0.19^{***}	-0.13
	(1.91)	(2.44)	(3.65)	(1.69)
Education in years	0.03	0.01	0.04	0.07
	(0.97)	(0.12)	(1.13)	(1.41)
Labor force participation	-0.15	0.06	-0.02	0.47
	(0.74)	(0.19)	(0.10)	(1.50)
Owner of dwelling	0.17	-0.10	0.34	-0.12
	(0.82)	(0.35)	(1.64)	(0.39)
Years living in dwelling (ln)	-0.04	0.18	-0.23^{*}	0.05
	(0.34)	(1.06)	(1.97)	(0.31)
Noise sensitivity	0.55^{***}	0.50^{***}	0.52^{***}	0.64^{***}
	(5.78)	(3.65)	(5.36)	(4.45)
Own air flights last year	-0.18	-0.26	-0.13	-0.26
	(1.12)	(1.12)	(0.79)	(1.10)
Mainz	1.59^{***}	1.53^{***}	1.32^{***}	1.36^{***}
	(8.33)	(4.99)	(6.91)	(4.43)
Constant	-28.39^{***}	-28.95^{***}	-29.13^{***}	-28.85^{***}
	(15.80)	(10.72)	(15.36)	(10.39)
McFadden R^2	0.39	0.39	0.36	0.38
No. of cases	2,611	2,611	2,611	2,611

Notes: Unstandardized logit coefficients with absolute z-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix S6

Factors affecting annoyance due to road traffic noise (OLS regressions, standardized regression coefficients).

Independent variables	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Road traffic noise Lden in dB(A)	0.43^{***} (25.72)	0.30^{***} (17.41)	0.36^{***} (21.19)	0.27^{***} (15.11)
Window quality	-0.13^{***} (7.51)	-0.30^{***} (17.31)	-0.13^{***} (7.27)	-0.25^{***} (13.66)
Environmental concern	0.09^{***} (5.06)	0.04^{*} (2.15)	0.07^{***} (4.20)	0.04 (1.96)
Income (divided by 1,000)	-0.03 (1.60)	-0.04^{*} (2.04)	-0.01 (0.56)	-0.02 (0.79)
Dwelling size in m^2 (divided by 10)	-0.02 (-0.99)	0.02 (1.01)	0.01 (0.03)	0.01 (0.17)
Sleeping room faces street	0.14^{***} (8.21)	0.12^{***} (7.18)	0.21^{***} (12.03)	0.16^{***} (9.02)
Dwelling with outdoor garden	-0.06^{***} (3.49)	-0.03 (1.79)	-0.06^{**} (3.17)	-0.03 (1.79)
Female	-0.01 (-0.62)	-0.03 (1.57)	-0.02 (1.15)	-0.03 (1.71)
Age in years (divided by 10)	0.10 (0.77)	-0.01 (0.10)	0.21 (1.59)	0.05 (0.38)
Age squared	-0.11 (0.81)	0.01 (0.09)	-0.21 (1.60)	-0.06 (0.43)
Education in years	-0.01 (0.24)	-0.01 (0.53)	0.01 (0.33)	-0.01 (0.22)
Labor force participation	-0.02 (0.91)	0.01 (0.68)	-0.01 (0.13)	0.03 (1.51)
Owner of dwelling	0.01 (0.50)	-0.01 (0.21)	0.01 (0.66)	0.01 (0.35)
Years living in dwelling (ln)	0.02 (0.76)	0.01 (0.24)	0.02 (0.77)	0.02 (0.69)
Noise sensitivity	0.16^{***} (9.46)	0.14^{***} (8.13)	0.19^{***} (10.85)	0.17^{***} (9.37)
Own car use	-0.01 (0.11)	-0.03 (1.59)	-0.03 (1.57)	-0.03 (1.31)
Mainz	-0.02 (0.95)	-0.04 (1.71)	-0.05^{*} (2.57)	-0.05^{*} (2.25)
Adj. R^2	0.31	0.27	0.29	0.23
No. of cases	2,611	2,611	2,611	2,611

Notes: Standardized regression coefficients with absolute t-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix S7

Factors affecting annoyance due to aircraft noise (OLS regressions, standardized regression coefficients).

Independent variables	Day, windows open	Day, windows closed	Night, windows open	Night, windows closed
Aircraft noise Lden in dB(A)	0.48***	0.42***	0.40***	0.38***
	(31.46)	(25.56)	(24.29)	(22.00)
Window quality	-0.09***	-0.18***	-0.09***	-0.15***
	(5.72)	(11.18)	(5.31)	(8.89)
Environmental concern	0.08***	0.06***	0.08***	0.06***
	(5.46)	(3.91)	(4.78)	(3.80)
Income (divided by 1,000)	0.03	0.05*	0.05*	0.05*
	(1.65)	(2.47)	(2.25)	(2.45)
Dwelling size in m^2 (divided by 10)	0.04*	0.06**	0.06**	0.07***
	(2.56)	(3.04)	(2.92)	(3.67)
Sleeping room faces street	-0.04*	-0.02	-0.02	-0.02
	(2.43)	(1.28)	(1.23)	(0.93)
Dwelling with outdoor garden	0.08***	0.08***	0.07***	0.09***
	(4.72)	(4.70)	(3.97)	(5.00)
Female	-0.01	-0.00	-0.00	0.01
	(0.97)	(0.06)	(0.29)	(0.47)
Age in years (divided by 10)	0.50***	0.53***	0.74***	0.68***
	(4.38)	(4.24)	(5.89)	(5.28)
Age squared	-0.32**	-0.35**	-0.54***	-0.51***
	(2.74)	(2.83)	(4.30)	(3.89)
Education in years	0.01	-0.01	0.01	0.01
	(0.34)	(0.65)	(0.75)	(0.37)
Labor force participation	0.01	0.01	-0.01	-0.01
	(0.33)	(0.49)	(0.43)	(0.29)
Owner of dwelling	0.05**	0.04	0.08***	0.05*
	(2.63)	(1.77)	(3.63)	(2.34)
Years living in dwelling (ln)	0.01	0.01	-0.02	-0.01
	(0.29)	(0.49)	(0.83)	(0.70)
Noise sensitivity	0.13***	0.10***	0.12***	0.11***
	(8.77)	(6.48)	(7.35)	(6.32)
Own air flights last year	-0.02	-0.02	-0.01	-0.01
	(1.42)	(1.31)	(0.65)	(0.64)
Mainz	0.24***	0.19***	0.20***	0.16***
	(13.90)	(9.78)	(10.70)	(8.31)
Adj. R^2	0.46	0.37	0.36	0.31
No. of cases	2,611	2,611	2,611	2,611

Notes: Standardized regression coefficients with absolute t-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix S8

Indirect effects of income (OLS regressions).

	Road traffic noise Lden in dB(A)	Aircraft noise Lden in dB(A)	Window quality	Dwelling size in $m^2/10$	Sleeping room faces street	Dwelling with outdoor garden	Owner of dwelling	Noise sensitivity
Income (divided by 1,000)	-0.30^{**}	-0.20^{***}	0.11^{***}	1.14^{***}	-0.04^{***}	0.04^{***}	0.06^{***}	0.05^{***}
	(2.75)	(3.86)	(7.17)	(24.67)	(6.10)	(5.81)	(12.06)	(3.99)
Environmental concern	0.24	-0.24^{*}	-0.06^{*}	-0.16	0.02	-0.01	-0.01	0.16^{***}
	(1.18)	(2.47)	(2.32)	(1.91)	(1.40)	(0.40)	(1.19)	(7.38)
Dwelling size in $m^2/10$					0.01			
					(0.39)			
Household size				2.01^{***}		0.11^{***}		
				(36.91)		(13.57)		
Female	-0.51	0.08	0.03	0.49^{***}	-0.01	0.05^{**}	0.02	0.05
	(1.67)	(0.58)	(0.65)	(3.77)	(0.61)	(2.64)	(1.35)	(1.59)
Age in years/10	-0.81	-0.64	0.11	-1.12^{***}	0.07	-0.03	0.12^{**}	0.18^{*}
	(1.05)	(1.78)	(1.10)	(3.42)	(1.48)	(0.63)	(3.21)	(2.16)
Age squared	0.03	0.06	-0.01	0.20^{***}	-0.01	0.01^{*}	-0.01	-0.02
	(0.33)	(1.54)	(0.36)	(5.56)	(1.86)	(2.25)	(0.66)	(1.78)
Noise sensitivity	-0.26	-0.13	-0.12^{***}	-0.07	0.01	-0.02		
	(1.48)	(1.60)	(5.07)	(0.98)	(0.06)	(1.51)		
Mainz	-0.73^{*}	1.95^{***}	0.01	1.28^{***}	0.03	0.14^{***}	0.35^{***}	0.21^{***}
	(2.24)	(12.71)	(0.31)	(9.35)	(1.43)	(7.17)	(22.81)	(5.76)
Constant	57.24^{***}	47.66^{***}	3.58^{***}	1.53^{*}	0.46^{***}	-0.10	-0.52^{***}	1.90^{***}
	(32.38)	(57.07)	(14.85)	(2.05)	(4.05)	(0.91)	(6.33)	(9.83)
Adj. R^2	0.01	0.09	0.04	0.43	0.02	0.11	0.25	0.04
No. of cases	2,611	2,611	2,611	2,611	2,611	2,611	2,611	2,611

Notes: Unstandardized regression coefficients with absolute t-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix S9

Factors affecting annoyance due to road traffic noise (OLS regressions without mediators).

Independent variables	Day, windows open	Day, windows closed	Night, windows open	Night, windows closed
Income (divided by 1,000)	-0.14**	-0.13***	-0.10	-0.09*
	(2.97)	(3.77)	(1.95)	(2.49)
Environmental concern	0.49***	0.24***	0.47***	0.23***
	(6.14)	(4.08)	(5.72)	(3.98)
Female	-0.16	-0.17*	-0.21	-0.18*
	(1.34)	(1.97)	(1.64)	(2.04)
Age in years (divided by 10)	0.37	0.08	0.74*	0.22
	(1.08)	(0.31)	(2.08)	(0.91)
Age squared	-0.06	-0.02	-0.10*	-0.04
	(1.51)	(0.83)	(2.47)	(1.38)
Education in years	-0.03	-0.02	-0.01	-0.02
	(1.14)	(1.28)	(0.41)	(0.85)
Labor force participation	-0.23	-0.01	-0.16	0.07
	(1.40)	(0.13)	(0.94)	(0.58)
Years living in dwelling (ln)	0.05	0.09	0.10	0.11
	(0.59)	(1.44)	(1.13)	(1.79)
Own car use	-0.41**	-0.35***	-0.53***	-0.31**
	(2.86)	(3.36)	(3.64)	(3.03)
Mainz	-0.02	-0.08	-0.18	-0.10
	(0.17)	(0.85)	(1.26)	(1.06)
Constant	2.90***	1.81**	1.04	0.86
	(3.72)	(3.21)	(1.30)	(1.54)
Adj. R^2	0.03	0.03	0.03	0.02
No. of cases	2,611	2,611	2,611	2,611

Notes: Unstandardized regression coefficients with absolute t-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix S10

Factors affecting annoyance due to aircraft noise (OLS regressions without mediators).

Independent variables	Day, windows open	Day, windows closed	Night, windows open	Night, windows closed
Income (divided by 1,000)	0.08	0.07*	0.13**	0.10**
	(1.88)	(2.11)	(2.91)	(2.74)
Environmental concern	0.33***	0.21***	0.32***	0.21***
	(4.47)	(3.62)	(4.25)	(3.59)
Female	-0.01	0.05	0.05	0.09
	(0.10)	(0.51)	(0.41)	(1.05)
Age in years (divided by 10)	1.13***	0.92***	1.71***	1.21***
	(3.54)	(3.59)	(5.29)	(4.78)
Age squared	-0.08*	-0.08**	-0.14***	-0.11***
	(2.31)	(2.60)	(3.95)	(3.69)
Education in years	-0.01	-0.03	0.01	-0.01
	(0.60)	(1.45)	(0.11)	(0.21)
Labor force participation	-0.03	-0.01	-0.13	-0.09
	(0.19)	(0.07)	(0.83)	(0.76)
Years living in dwelling (ln)	0.23**	0.22***	0.16*	0.15*
	(2.85)	(3.34)	(2.00)	(2.33)
Own air flights last year	-0.28*	-0.20	-0.18	-0.13
	(2.18)	(1.92)	(1.40)	(1.27)
Mainz	2.64***	1.65***	2.30***	1.50***
	(21.95)	(17.13)	(18.86)	(15.73)
Constant	-2.94***	-2.54***	-5.07***	-3.70***
	(4.04)	(4.37)	(6.89)	(6.42)
Adj. R^2	0.21	0.15	0.18	0.13
No. of cases	2,611	2,611	2,611	2,611

Notes: Unstandardized regression coefficients with absolute t-values in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix S11

Robustness analyses

To check for the robustness of our models in Table 3 and 4, we followed a procedure suggested by Young and Holsteen (2017), using the STATA software package mrobust.ado. In the following, we present robustness analyses for the effects of window quality, environmental concern and income, because these effects constitute the essential topics of our paper. The Young and Holsteen approach estimates modelling distributions based on all combinations of controls in the model and can also identify to what extent each additional variable in the model affects the variable of interest, in our case window quality, environmental concern and income.

Tables S11.1, S11.2 and S11.3 show robustness indicators for the full models in Table 3 and Table 4 of the main text. Focusing on window quality (S11.1), environmental concern (S11.2) and the income effects (S11.3), the tables give the robustness ratio, sign stability and significance rate. The robustness ratio considers the "preferred estimate" and total standard error based on models of all possible combinations. Similar to the t-value, a robustness ratio value larger than two suggests robustness. Sign stability refers to the share of estimates of the robustness analysis that show a similar sign of the effect. The significance rate refers to the share of significant effects across the robustness analysis.

The results presented in Table S11.1 indicate very robust effects of the variable window quality on road traffic and aircraft noise annoyance. For all models, the robustness ratios are well above the value of two, and sign stability as well as significance rates amount to100%.

As can be seen in Table S11.2, the effects of environmental concern are also robust. For all models, the robustness ratios are above the value of two, sign stability is 100% and the significance rate ranges between 95% and 100%.

For road traffic noise annoyance, Table S11.3 yields the result that the income effects are not very robust, especially in the models for "night, open windows" and "night, closed windows." While the robustness ratios for the day-time models are close to a value of two, the sign stability is 100% and significance rates are 68% and 76%, the robustness ratios for the night-time models are well below a value of two, sign stability amounts to 76% and 87% and significance rates are 14% and 24%. This supports our finding that parts of the income effect are mediated by variables included in the models of Table 3. Additional robustness analyses (not shown here) for the models without mediators, i.e. the models in the table of Appendix S9, indicate robust income effects: robustness ratios greater than two, 100% sign stability, and a significance rate that ranges between 81% and 100%. For aircraft noise annoyance, Table S11.3 shows that the full models are very robust regarding the income effects: robustness ratios greater than 12, 100% sign stability, and significance rates of 100%.

Table S11.1

Robustness analyses for the window quality effects, including robustness ratio (first value), sign stability (second value) and significance rate (third value).

Independent variables	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Full models on road traffic noise annoyance, Table 3 in main text	-6.518 100% 100%	-15.045 100% 100%	-5.981 100% 100%	-11.612 100% 100%
Full models on aircraft noise annoyance, Table 4 in main text	-3.854 100% 100%	-8.193 100% 100%	-3.659 100% 100%	-6.538 100% 100%

Table S11.2

Robustness analyses for the environmental concern effects, including robustness ratio (first value), sign stability (second value) and significance rate (third value).

Independent variables	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Full models on road traffic noise annoyance, Table 3 in main text	4.734 100% 100%	2.557 100% 98%	4.048 100% 100%	2.406 100% 94%
Full models on aircraft noise annoyance, Table 4 in main text	3.237 100% 99%	2.637 100% 95%	3.267 100% 100%	2.901 100% 97%

Table S11.3

Robustness analyses for the income effects, including robustness ratio (first value), sign stability (second value) and significance rate (third value).

Independent variables	Day, open windows	Day, closed windows	Night, open windows	Night, closed windows
Full models on road traffic noise annoyance, Table 3 in main text	-1.806 100% 68%	-1.857 100% 76%	-0.563 76% 14%	-0.776 84% 24%
Full models on aircraft noise annoyance, Table 4 in main text	17.717 100% 100%	15.374 100% 100%	13.424 100% 100%	14.268 100% 100%

Reference for Appendix S11

Young, C., Holsteen, K., 2017. Model uncertainty and robustness: A computational framework for multi-model analysis. Sociological Methods and Research 46, 3-40.