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Sick of Noise: the Health Effects of Loud Neighbours and Urban Din

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October 2015

Abstract: Urban residential neighbour noise is ubiquitous but its effects are relatively under-researched. Neighbour noise is difficult to measure and is often locally controlled under nuisance, rather than environmental health, regulations. We analyze the health effects of residential noise annoyance using a high quality longitudinal survey of over 5000 adults in the Netherlands between 2007 and 2013. We find surprisingly widespread health effects of residential noise annoyance, with neighbour noise relatively more damaging than street noise. To address endogeneity concerns with cross sectional analysis we then exploit the time dimension of the panel and employ conditional fixed effect logistic estimation to control for unobservable time-invariant characteristics of individuals, conditioning only on initially healthy respondents to mitigate concerns of reverse-causality. We continue to find surprisingly strong and robust effects of neighbour noise annoyance on a variety of health outcomes including cardio-vascular symptoms, joint and bone disease, and headache.

Keywords: Noise pollution, health, logistic regression
JEL codes: Q53, I18, R41, D62

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1. Introduction

Residential noise pollution is a common urban irritant, and where urban din can be objectively measured, such as for traffic and airport related noise, studies have found links to both lowered subjective well-being (van Praag and Baarsma 2005) and health effects such as stress, cardio-vascular problems, stroke and sleep disruption (Sørensen *et al*. 2011, Babisch 2011, 2014, Evans *et al*. 1998, 2001, Ising and Braun 2000). Indeed, in their review of the evidence, Hammer *et al.* (2014) estimate that tens of millions of Americans may be at risk of heart disease and other noise-related health effects.

However where residential noise is less easily measured, as in the case of noise from neighbours, there has been much less research. This dearth of evidence is understandable given that studying the effects of neighbour noise is methodologically quite challenging. Unlike traffic or airport noise, loud neighbours are often unpredictable and not generally *ex ante* observable. Thus the presence of loud neighbours may not manifest itself in the form of property values or other economic tangibles, making it difficult to value the benefits of increased night patrols or acoustic building requirements. Furthermore, until recently there was little theoretical reason to distinguish between noise pollution from loud neighbours and that from other urban sources. The relative lack of evidence has led most national noise regulation to focus on (easily 'observed') airport, construction, traffic and work-related exposure to noise (Hammer *et al.* 2014, Nelson *et al*. 2005). Enforcement of neighbour noise laws, where they exist, often falls under the purview of local nuisance laws rather than under environmental health authorities and is largely left to local governments with varying degrees of prioritization and effectiveness (Hammer *et al.* 2015).

Nevertheless there are good theoretical reasons to suspect that neighbour noise could additionally affect health through channels not captured in studies of traffic and airports; noise from loud neighbours is quite different than that from streets in that it is more unpredictable and has very high informational content, even if the decibel level is similar or even lower (Neimann *et al*. 2006). Thus the potential biological and psychological mechanisms that link each type of noise to health (and subjective well-being) are distinct.

This paper contributes to the body of evidence on the effects of noise by analyzing the health effects of self-reported residential noise annoyance, distinguishing between that from neighbours and that from roads, in a high quality random survey of over 5000 adults in the Netherlands between 2007 and 2013. Respondents were asked a multitude of detailed questions about many aspects about their home, health, economic, and social lives at different points in time, making it feasible to control for a wider range of potential socio-economic and behavioral confounders than has been feasible in previous cross-sectional studies. In addition, the longitudinal dimension of the dataset allows us to conduct the first (to our knowledge) time-series analysis of the effects of self-reported noise annoyance on health, controlling for individual fixed effects to control for time-invariant unobservable characteristics and conditioning only on initially healthy respondents to mitigate concerns about reverse-causality in the cross section.

In the cross section we find strong correlations between exposure to noise and a variety of health outcomes, including cardio-vascular disease, lung disease, auto-immune diseases such as arthritis and bone disorders, as well as fatigue and headache. These effects largely persist even when sleep disturbance (also strongly correlated with residential noise annoyance) is controlled for, and neighbour noise is largely found to be relatively more harmful than street noise (though the total health effects of nearby busy streets must take into account that caused by air quality as well). When we control for potential endogeneity concerns using conditional fixed effects estimation in the panel these findings from the cross section remain relatively robust. Overall our analysis strongly suggests that everyday urban residential noise annoyance, especially from noisy neighbours, could contribute to a surprising variety of health disorders and that further research is needed.

The paper proceeds as follows: in section 2 we briefly review the existing literature on the health effects of noise; in section 3 we describe the data and estimating method; in section 4 we discuss the cross sectional results and in section 5 we discuss the fixed effects panel data results. Section 6 summarizes the findings and concludes with a discussion of the implications both for urban policy and for future research. Results are presented in the Tables Appendix.

2. Health and noise

Residential noise can definitely be an irritant and studies have shown urban noise pollution to be associated with lower overall life satisfaction (Weinhold 2013, van Praag and Baarsma 2005). However less is known about how it could affect physical health. Early research on the relationship focused on the effects of work-related exposure to noise on hearing (see, for example Olishijski and Harford 1975, Schori 1976, or more recently Nelson *et al*. 2005). This literature generally concluded that exposures below about 80 dB(A) (approx. the noise of a garbage disposal) are safe, with these consensus thresholds reflected in workplace noise standards adopted in many countries (e.g. ISO 1999).

More recently there has been growing evidence that that the physiological effects of noise potentially extend to many more dimensions of health, and at much lower dB(A) levels of exposure, than had previously been recognized. For example, Sørensen et al (2011) explores the link between road traffic noise and stroke, while Sørensen et al (2013) analyze its effect on diabetes. Babisch (2014) provides a meta-analysis of 14 recent cross-sectional and case control studies of traffic noise and coronary heart disease, finding a statistically significant 8% increase in risk for every additional increase of 10 dB(A) traffic noise (within the range of 52-77 dB(A)). Evans et al. (1998, 2001) and Ising and Braun (2000) find significant increases in stress hormones released during sleep in both children and adults exposed to moderate street noise (over 60 db(A)). More broadly, a number of medical studies link mental stress to immunological and cardiovascular reactions in humans (see Neimann et al. 2006 for a good survey) and an expanding literature demonstrates the negative effects of noise annoyance on reported well-being (e.g. Weinhold 2013). WHO (2011) synthesized the existing evidence in order to estimate the years of healthy life (DALYs) lost to noise in Europe; the peer-reviewed chapters (each authored by experts in that field) estimate 61,000 years lost due to ischemic heart disease; 45,000 years lost to cognitive impairment in children; 903,000 DALYs lost due to sleep disturbance; 22,000 years lost to tinnitus; and 654,000 years lost due to noise induced annoyance.

When it comes to neighbour noise the relationship to health may be even more complex. Leventhall (2004) points out that low frequency noise can be a particular problem for people in their homes, with "learned aversion" easily leading to annoyance and stress at decibel levels that may not fall within existing regulations. Furthermore, as Neimann *et al.* (2006) explain,

> Usually, neighbourhood noises are sounds with high information content such as language, music or also the noise of footsteps. It is in the nature of humans to have their attention drawn to such informative sounds, even if the sound level is relatively low. The annoyance potential of neighbourhood noise is therefore relatively high also at low noise levels and is heightened by the hearer's knowledge of the sound producer and other things causing the noise. (p. 64)

Thus the established relationship between noise, sleep-disruption induced endocrine abnormalities, and stress hormone reactions all provide plausible biological mechanisms linking noise disturbances, even at relatively low decibel levels, to a host of health problems, including cardiovascular, immunological, and even blood sugar regulation issues (Babisch 2003, Ising and Kruppa 2004, Hammer *et al.* 2014). However, as these mechanisms may operate very differently from the kinds of physiological effects caused by specific levels of artificial noise observed in laboratory settings, it is challenging to systematically gauge the prevalence, if any, of the effects of real-life everyday residential noise annoyance on health.

Some economists may find the concept of costs from chronic residential noise annoyance something of a mystery; if there is an environmental problem that threatens health, why don't people move? The disamenity should be reflected in house prices and people should self-select into noisier (but cheaper) or quieter (but pricier) homes as per their levels of tolerance. However, in practice there are a number of reasons why people may not be able to self-select away from noisy neighbours so easily. First, in many areas moving costs are very high; for example in the UK a 'stamp duty' of up to 12% of the purchase price of homes reduces property transactions by between 8-20% (*Economist* 2015). Indeed, a UNHSP report found 33 of 35 European countries surveyed employ some kind of property transfer tax, and among these the transfer tax employed in the Netherlands was rated 'High.' (UNHSP 2013). Van Praag and Baarsma (2005) investigated the impact of airplane noise on housing prices in Amsterdam and found that housing was so rationed, and moving so difficult, that the disamenity of airplane noise was absorbed not in housing prices but exclusively as a 'residual' in the life satisfaction of homeowners. Furthermore, neighbour noise is not an *ex-ante* observable characteristic of housing stock; thus any move might result in a metaphorical leap from the pot into the fire. Noisy neighbours may also eventually move away, or grow up, so the decision to move or to stay is a highly probabilistic one, further raising the cost. Finally, as the link between noise and health is subtle, most people may arguably be unaware of the full cost of noise; they may consider it a nuisance but not understand the long term consequences.

Thus in practice people may remain exposed to noisy neighbours despite the potential long term toll. Indeed, despite the methodological challenges, the empirical studies that have been done to date provide suggestive evidence that the health impact of residential noise could be surprisingly widespread. The first large epidemiological study on the health effects of chronic annoyance by neighborhood noise was carried out in 2003-2004 by Niemann and Maschke for the World Health Organization (WHO) as part of its Large Analysis and Review of European Housing and Health Status (LARES) (Niemann and Maschke 2004, Neimann *et al*. 2006). Niemann and Maschke (2004) examined the cross-sectional relationship between noise exposure and health outcomes in a sample of about 8000 adults and children across Europe, finding elevated risks of exposure to neighborhood noise associated not only with psychological depression, but also in the cardiovascular, respiratory and musculoskeletal systems, with the particular risks displaying a strong dose-response effect that varied significantly between children, adults and the elderly (but independent of socio-economic and housing conditions).

The limited number studies on residential noise and health to date have all relied on cross-sectional variation to draw inferences, using either multivariate regression or matching techniques to attempt to control for confounding variables, and thus omitted variable and endogeneity bias remains a serious concern. This paper extends this literature by (a) including a broader set of environmental and socio-economic control variables in cross sectional analysis to control for more potential confounders; and (b) by providing the first (to this author's knowledge) analysis of self-reported residential noise and health in panel data, using individual fixed effects to control for both observable and unobservable time-invariant characteristics that could be correlated with both noise exposure and health outcomes and thus confound cross sectional studies. In addition, the longitudinal nature of the data further allow us to restrict our analysis to initially healthy respondents, mitigating concerns about reverse-causality in earlier studies.

3. Data and Method

Data for the analysis come from the Longitudinal Internet Studies for the Social Sciences (LISS) panel administered by CentERdata (Tilburg University, The Netherlands). The LISS CentER data is based on an internet-based longitudinal survey from 2007-2013 of over 8000 individuals that was designed for "scientific, policy or socially relevant research." The quality and the coverage of the sample was of prime concern; participants were identified using a true probability sample drawn from the Dutch population registers by Statistics Netherlands and recruitment was by repeated contact via phone and/or in person, resulting in an enrollment rate of 48% of the total initial sample, including households with no internet connection as a computer and connection were provided as needed. Scherpenzeel (2009) conducts a detailed evaluation of the sampling method and resulting representativeness of the LISS panel, finding that the LISS sample compares favorably to high-standard traditional surveys (for more detail on the LISS panel, see Scherpenzeel, A.C., and Das, M. (2010) or visit www.lissdata.nl).

There are only 65 observations in the LISS data on children born before 1990 so we omit this category and focus only on those respondents over 17 years of age in 2007 when the survey started, ending up with a total sample size of 5243 (though not all respondents answer all questions, or respond in all years, so sample size varies by regression). In the Health module of the LISS respondents were asked both general and specific questions about their health. *Self reported health level* is the answer, from 1 (poor) to 5 (excellent) to "How would you describe your health, generally speaking?" Respondents were also asked about specific problems and diseases by allowing them to select from a list of possibilities to address such questions as, "Do you regularly suffer from:"; "Are you currently taking medicine at least once a week for:"; and "Has a physician told you this last year that you suffer from the following diseases/problems?". Respondents were coded with a specific health problem if they indicated in the affirmative with respect to that health problem to any of these questions. Specifically, health problems were coded as cardio-vascular; joints & bones (including arthritis and skeletal problems); lung disease (including bronchitis), asthma, diabetes, stroke, blood pressure, cholesterol, fatigue and headache (including migraine). In addition respondents noted whether they suffered from sleep disturbance (from any cause).

The main explanatory variables of interest are binary responses to the question "Are you ever confronted with the problems listed below in your home environment?" *Neighbor Noise* takes the value 1 if respondents indicated 'noise annoyance caused by neighbors', and 0 otherwise. *Street Noise* takes the value 1 if respondents indicated 'noise annoyance caused by factories, traffic or other street sounds,' and 0 otherwise. Finally, to control for poor air quality associated with being near a busy road or factory, *Bad Air* takes the value 1 if respondents choose 'stench, dust or dirt, caused by traffic or industry,' and 0 otherwise.

Additional control variables include information on gender, age, whether the respondent has ever smoked, whether they consume more than one alcoholic drink per day, body mass index (BMI), education level (from primary to university level, 1-4), marital status, labor market status, number of hours worked, monthly household income, number of children in the household, and whether the respondent is religious. In addition a number of control variables describe the neighborhood and dwelling, including whether the neighborhood is very urban, moderately urban (control), or rural, whether the respondent has experienced vandalism or crime at home, and whether the respondent finds the dwelling to be too small, too dark, too damp, too cold, has a leaking roof, or has rotten window frames or floors. Table 1 presents summary statistics of all the cross-sectional average of all variables used in the analysis.

Most of the health variables of interest are binary; respondents either have the condition in a particular year, or they do not. To be consistent with the literature and facilitate comparability with others' results we model the probability that an individual will develop the condition as a logistic function and estimate the model using maximum likelihood logistic regression. The conclusions we draw are robust to this choice of functional form - linear probability methods (LPM) give similar results, but the LPM coefficient estimates are not easy to compare to the existing literature. Thus the model takes the form:

(1) $\text{logit}(p_i) = \log(p_i/(1-p_i)) = \beta_0 + \beta_1 * x_{1i} + ... + \beta_k * x_{ki} + u_i$

where p is the probability of disease, x_{1i} - x_{ki} are the k possible explanatory and control variables, and β_0 - β_k and the k coefficients. By themselves, the logistic coefficient estimates $\hat{\beta}_k$ are not straightforward to interpret, but the monotonic transformation $OR_k = e^{\hat{\beta}_k}$ yields the odds ratio (OR) of variable x_i which gives the ratio of the likelihood of disease with and without the factor x_i (if x is dichotomous), or for a one-unit increase in a factor x_i (if x is continuous). Odds ratios thus range from 0 to infinity, with values below 1 indicating that the factor x_i has lowered the odds of disease, and values above 1 indicating that it has increased it. For example, in regression (1) of table 3A we report that the odds ratio of exposure to neighbour noise for cardio-vascular disease is 1.38, meaning that, all else equal, the odds of cardio-vascular disease for those with rude neighbours is 1.38 times the odds for those with more polite folks nearby. In the same regression we find an odds ratio for body mass index (BMI) of 1.05, meaning that the odds of cardio-vascular disease will increase by 5% for every one unit increase in BMI.

As discussed above, one reason most previous studies have focused on road and airport noise is that it is easier to obtain objective measures for these compared to, for example, intermittently loud neighbours. This study, on the other hand, uses subjective data and a primary concern would be that unobserved individual characteristics (such as irritability or excessive sensitivity) could largely determine both self-reported noise annoyance as well as self-reported health. In other words, variation in our variable of interest, neighbour noise, may not be exogenous. We attempt to mitigate this concern in section 5 by exploiting the panel nature of the data to control for individual fixed effects, but this potential source of endogeneity cannot be entirely eliminated; in particular, if illness changes people's sensitivity to noise we could observe a spurious *within* correlation between noise complaints and illness. To the extent that we observe this correlation for some illnesses and not for others this heterogeneity of effects offers us a partial argument that the observed relationships are likely not spurious (or they would more likely be observed for all or most illnesses), but we cannot entirely rule it out and thus this possible source of endogeneity remains a caveat to all our results.

Another critique of this approach is that we do not observe the objective magnitude of the noise. However the biological mechanisms linking residential noise to health outcomes operate primarily through sleep disturbance and stress (including unconscious stress) that are related not only to the decibel level of noise but also to its timing, frequency, and information content. Biological and psychological triggers could be set off by different degrees of these various characteristics of noise for different people. In the presence of such heterogeneous responses to any given (homogenous) noise, self-reported subjective noise annoyance in effect captures the underlying heterogeneity in the responses themselves. We report strong correlations between health outcomes and subjective noise annoyance here and leave it to future research to implement a (likely more expensive) study design to distinguish the effects of objective noise measurements.

4. Cross Sectional Analysis

The cross-sectional pan-European WHO-LARES study conducted by Niemann and Maschke (2004) along with their extended analyses using the same data in Neimann et al. (2006), and Maschke and Niemann (2007) are the only previous studies (to our knowledge) to have looked at the correlation between self-reported noise nuisance and health outcomes. Their independent variables of interest, exposure to residential noise, are quite detailed on noise from a variety of sources, with annoyance from each ranked as either 'not at all,' 'moderately' or 'strongly.' They further include set of individual control variables such as age, gender, BMI and smoking, exercise and drinking habits, but socio-economic factors were controlled for using housing characteristics only, such as overall satisfaction with the residential area and indicators of light, damp, and temperature within the dwelling. Niemann and Maschke also control for (self-reported) indoor air quality as part of the assessment of housing quality, but it is not clear that they recognized the potential relationship of air quality with road noise.

Our LISS data differs in that the sample is drawn entirely from the Dutch population, and therefore could be thought of as more homogeneous. Furthermore we have much more detailed socio-economic information on respondents; in addition to similar indicators of housing quality as used in Niemann and Maschke we have data on household income, education level, and marital and labour market status. However our data on noise exposure is rougher; we only have the binary response of whether the respondent is exposed to annoying neighbour or road noise, or not. Overall, with many more socio-economic control variables and less detailed information on the level of noise annoyance we would expect it to be more difficult to detect any relationship between noise and health in the LISS data compared to the WHO-LARES sample.

As the LISS data is longitudinal, for our initial cross sectional analysis we compute the average value of each non-missing variable for each respondent over the sample period 2007-2013. Not every respondent answered each question in every year (and many questions were only put in waves in certain years) so this approach maximizes the sample size, with clustered standard errors used to mitigate inference bias caused by differences in the number of underlying data points averaged for each individual. This also implies that values for some of our dichotomous variables may fall between 0 and 1 if the value changes over time.

In all cases we control not only for neighbour and street noise, but also for (self-reported) air quality, which we call *bad air*. However as described above our control for air quality is a simple dichotomous variable; less obvious (but perhaps more deadly) tiny particulate types of air pollution may not be apparent to respondents. Indeed, Lipfert et al. (2006) shows that road noise can be used as an effective proxy for air quality where objective measures of the latter are missing. Thus any effects we find associated with street noise annoyance may also include any health impact from the associated poorer air quality, and we want to take care to interpret the results associated with street noise as including both the noise-only effect as well as any unobservable air quality effect.

Table 2 reports the cross sectional OLS results of residential noise annoyance and self-reported health level, ranked from 1 (poor) to 5 (excellent). Both neighbour and street noise as well as bad air are negative and statistically significant. Column (2) provides the standardized betas to give us some sense of comparability across different types of determinants of health level. Consistent with existing studies we find BMI and age to be major factors in declining health level, while household income is strongly and significantly positive. Exposure to neighbour noise is surprisingly important; in terms of impact it has approximately the same order of magnitude on lower health as ever having smoked.

Tables 3A and 3B then present odds ratios from logistic regressions of various kinds of disease categories. In table 3A we find neighbour noise to be strongly significantly associated with both cardio-vascular (column 1) and lung disease (column 5) with odd-ratios of 1.38 and 1.49 respectively, that fall between those obtained by Niemann and Maschke (2004) for 'moderate annoyance' and 'strong annoyance' of neighbourhood noise in adults for 'cardio-vascular symptoms' (OR=1.3 and 1.6, respectively) and 'bronchitis' (OR=1.0 (not statistically significant) and 1.9). Odds ratios for cholesterol, blood pressure and asthma are all greater than one, but are not statistically significant, which is again mostly consistent with Niemann and Maschke's results, although their estimate for blood pressure ('hypertension') is significant.

In table 3B we find significant positive effects of neighbour noise on 'joints and bones' (column 6), fatigue (column 9) and headache (column 10), with odds ratios of 1.67, 3.78 and 1.52 respectively. These again fall in between the estimates obtained by Niemann and Maschke for moderate and strong annoyance of neighbourhood noise on 'arthritis symptoms' (OR=1.3 and 2.3 respectively), and 'migraine' (OR= 1.2

and 1.8). Also consistent with the WHO-LARES study we find effects of noise on diabetes and stroke to be statistically insignificant (and less than 1). As there is no analogue in the Niemann and Maschke results for 'fatigue' we cannot compare, but the large OR of 3.78 that we obtain would likely be considered quite credible by anyone who has dealt with loud neighbour problems...

Thus overall our results are remarkably similar to those obtained by Niemann and Maschke (2004) with completely different data. We find statistically significant relationship between neighbour noise annoyance and cardio-vascular symptoms, lung disease, joint and bone problems, fatigue and headache. Our point estimates of the associated odds ratios fall just between the Niemann and Maschke's OR estimates for 'moderate' and 'strong' annoyance to neighbourhood noise, and both our studies fail to find statistically significant effects on diabetes incidence, stroke, or asthma. Although not all our results are directly comparable; - Niemann and Maschke do not look at fatigue or cholesterol - the only slight difference in our results is a difference in statistical significance in the impact on blood pressure.

As in Niemann and Maschke our estimated odds ratios for the effect of street noise on health outcomes are lower than those for neighbour noise and less (and sometimes not) statistically significant. This may partially be due to the strong correlation between street noise and air quality; some of the pure effects of noise may be captured in the *bad air* variable (or vice versa). This result also suggests that studies that focus solely on air quality (or, less commonly, solely on street noise) should control for the contribution of the other. In practice it is likely very difficult to fully isolate the effect of road noise from that of air pollution in dwellings exposed to busy roads.

Following Niemann and Maschke, in tables 4A and 4B we analyze the effects separately by age group (though we do not have children *per se* in our sample), dividing the sample into middle aged respondents (aged 30-66 in 2007), young (aged 17-29) and old (aged 67+). Again, consistent with the WHO-LARES study, we find the effects of noise on the health of the young and old to be considerably less; at most noise causes young people (likely mild) headaches, while there was some effects noted in the older sample (higher likelihood of headache and, surprisingly, perhaps asthma).

4.1 Sleep Disturbance

One of the likely mechanisms through which noise can impact health is through sleep disturbance (Ising and Braun 2000, Neimann et al. 2006). In table 5A and 5B we explore whether sleep disturbance could explain the health outcomes reported in tables 3 and 4; to keep the tables concise we focus only on middle age respondents (30-66 years old in 2007) and suppress the results for the full set of control variables (available upon request). Column (1) of table 5A shows that, consistent with the literature, neighbour noise and street noise annoyance are both large and highly significant predictors of sleep disturbance (while *bad air* is not).

Columns (2)-(11) then additionally explore the impact from residential noise on health outcomes controlling for sleep disturbance (from any cause). Consistent with the literature we find that sleep disturbance is a large and important contributor to many poor health outcomes, more or less doubling or trebling the odds for just about everything (though this may be an endogenous relationship in some cases).

Contrary to expectations, however, the estimated odds ratios for neighbour noise remain still greater than 1 and statistically significant for cardio-vascular disease, lung disease (although in this case the significance falls quite a bit, remaining barely significant at 10%), joints and bones, fatigue and headache. Controlling for sleep disturbance better eliminates the effects of street noise; it is no longer significant for lung disease and the both the magnitude and statistical significance of its effects on joints and bones and headache is reduced. To this author's knowledge this is the first analysis to directly separate the health effects of noise above and beyond the effects of related sleep disturbance (from noise or any other cause). We find that the (high-information) noise caused by neighbours seems to have a stronger additional effect on health, compared to the relatively information-free noise caused by traffic, providing some additional support to the idea that some kinds of relatively low-decibel noise sources can nevertheless be detrimental both to well-being and health.

5. Logistic Panel Data with Conditional Fixed Effects Analysis

The cross sectional results presented in section 4 provide surprising suggestive evidence of the impact of residential noise on health outcomes. They are consistent with the (single) existing WHO study of neighbour noise and health, while providing added confidence in the findings by controlling for additional socio-economic variables. We further provide evidence that the impact of neighbour noise in particular is to a large part through mechanisms other than, and additional to, that of sleep disturbance.

Nevertheless there could still be confounding unobservable omitted variables driving the results. In particular, as annoyance has been widely identified as playing a linking role between noise and health, some people could be particularly prone to annoyance, which would lead them both to report more noise annoyance on surveys and - through the very stress responses discussed above - contribute to the development of various disease outcomes. Furthermore, it may be that illness itself could increase annoyance and/or sensitivity to noise.

To attempt to address these concerns we exploit the fact that the LISS is a longitudinal survey, with respondents answering questions on health and noise in up to five different years (with an average for the sample of between 2 and 3 for most disease outcomes). Thus we are able to look to see whether the likelihood of disease outcomes increases when individuals are exposed to noise, compared to when *the same individuals* are not exposed to noise. By controlling for individual fixed effects, we effectively eliminate the effect of unobservable time-invariant characteristics that could confound the cross-sectional analysis. In the time-series analysis we only extract information from changes over time in our variables of interest for the same individual, so the chronically annoyed person will report noise in all time periods and information from their observations will thus be dropped from the analysis.

However, not all questions on health and noise were asked in the same years, and not all respondents participated in all years. Thus we modify our definition of 'exposure to noise' to include whether a respondent reports exposure to noise in either the current year or in either of the previous two years (in other words, at any time in the last three years). This seems sensible not only to increase the sample size, but it may be that the health impact of new noise exposure manifest over time with a lag and this will allow us to capture such effects. Finally, to mitigate problems of reverse causality we restrict the sample to only those individuals who were healthy (with respect to the particular health outcome of interest) in the previous two years prior to the current year. Thus we model whether respondents who have experienced a (past 2 years or current year) change in noise exposure are more likely to develop a new health problem compared to those years in which there was no (past or current) change in their noise exposure. Data from respondents who experience noise continuously before their health changes (or do not experience noise at all) will not contribute to the estimates, nor will information from respondents who fall ill before a noise change.

There is a lively theoretical and empirical literature on the advantages and disadvantages of alternative fixed effects models with binary dependent variables (Allison 2009). Following Allison (2009) and the recommendations of the Stata XT manual, we employ conditional fixed effects logistic regression (although again the results are not overly fragile to the choice of functional form as similar conclusions are derived from a linear probability model with fixed effects). Conditional fixed effects logistic (FE logit) estimation has an additional advantage of producing comparable odds ratio estimates, making the output easily comparable both to the cross-sectional results as well as to the existing (all cross sectional) literature. Thus we have:

$$(2) \qquad \text{logit}(p_{it}) = \log(p_{it}/(1-p_{it})) = \beta_i + \beta_1 * x_{1it'} + \ldots + \beta_k * x_{kit'} + u_{it}$$

where β_i denotes the individual-specific fixed effect and t' denotes the current and previous 2 year time period.

All time-invariant variables are controlled for by the fixed effects; as a result the sample size increases slightly as we can include respondents who did not answer some of the questions associated with time-invariant control variables from the cross section. We do include as controls other time-varying variables that could be correlated with changes in health and exposure to noise, namely exposure to poor air quality, marital status and labour market status. Although we do not have location data and thus cannot tell if respondents have moved or not, we also control for the full set of dwelling characteristics in order to control for changes in housing quality. As with the noise variables we define each as taking the value 1 if the specific characteristic was noted in either the current or previous 2 years. Finally, as to some extent the marital and labour variables may be endogenous to health outcomes we verify that the results on noise pollution remain robust to excluding these and only controlling for dwelling characteristics (results not reported but available upon request).

Although the conditional fixed effects panel estimation mitigates many potential endogeneity biases of cross sectional analyses, a number of caveats to the estimation should be emphasized. In particular, compared to the cross sectional analysis, the effective sample size for the fixed effects estimates is greatly reduced as information can only be extracted from respondents whose health status has changed. This reduced sample size, combined with the fact that our binary noise measure is less precise than the 3-point scale used by Niemann and Maschke[10], should make it more difficult to detect any health effects of noise. In addition there still could be unobserved time varying covariates correlated with both health and noise annoyance that could bias the results or, as discussed above, some illnesses could make respondents more noise-sensitive. Thus while the panel fixed effects analysis provides an additional channel through which to explore the relationship between noise and health, it still does not entirely eliminate potential problems of endogeneity.

Table 6 presents regular OLS panel data fixed effects analysis of self-reported overall health level on our measures of residential noise annoyance, air quality, and dwelling, marital and labour market characteristics. We find only street noise and bad air is significantly detrimental to self-reported health, an effect which is not diminished when we further control for sleep disturbance (which by itself is highly significant and negative) in column (2).

However, when we examine individual health outcomes in Table 7 we find the odds ratios associated with neighbour noise remain greater than 1 and statistically significant for cardio-vascular disease, joints and bones, and headache. In addition, now controlling for individual fixed effects, we detect a relatively large effect of neighbour noise on cholesterol. The estimated effect on lung disease however is now less than one, indicating that neighbour noise is associated with *lower* odds of lung disease, though this is significant only at 10%. Note however that the sample size for each of these columns is relatively small; for lung disease there are only 185 observations in the analysis. Indeed, there were too few observations to estimate effects for arthritis, diabetes, asthma or stroke. As there are even fewer individuals that experience changes in dwelling characteristics (except leaks, which apparently come and go) than experience changes in noise exposure, it is not surprising that most of these control variables are statistically insignificant.

Notably, the results from Table 7 column (7) confirm that having new rude neighbours hugely increases the likelihood of headaches.

Table 8A and 8B additionally explore the roll of sleep disturbance. To keep the table parsimonious we suppress the coefficients on the control variables of dwelling, marital and labour market status (available upon request). Column (1) finds neighbour noise to be large and highly statistically significant factor in sleep disturbance. In column (2) we find that while sleep disturbance is highly predictive of cardio-vascular disease, controlling for sleep problems has significantly reduced the magnitude and significance of the effect of neighbour noise, which is no longer statistically significant at standard levels. Thus we find strong suggestive evidence that sleep disturbance could be a primary mechanism through which neighbour noise and cardio-vascular disease are linked.

However, as the results in Table 8A column (3) and Table 8B columns (6) and (8) show, neighbour noise is still correlated with cholesterol, joint & bone problems, and headache even after controlling for sleep disturbance. In addition, sleep disturbance greatly increases the odds of lung disease, and the direct effects of noise are no longer significant.

6. Discussion

Loud and/or rude neighbours are an under-appreciated cause of misery and, apparently, health problems for many urban residents. Unlike other more visible dwelling characteristics, the presence (or new appearance) of loud neighbours cannot be easily observed or predicted in advance when purchasing or renting a new place to live. Faced with noisy neighbours and unsympathetic regulators, choices are few; beyond constituting a source of stress, we observe large, statistically significant correlations between residential noise exposure and myriad health outcomes.

This paper extends the literature on residential noise and health by (a) including a broader set of environmental and socio-economic control variables in cross sectional analysis than previous studies on self-reported residential noise and health; and (b) by providing the first (to this author's knowledge) analysis of self-reported residential noise and health in longitudinal panel data, using fixed effects to control for unobservable time-invariant characteristics of individuals (such as a tendency towards annoyance) and restricting the analysis to respondents who are initially healthy to mitigate the possibility of reverse causality, both potential problems that could confound cross sectional analyses.

While we cannot rule out the possibility that unobserved time varying omitted individual characteristics could affect both self-reported noise annoyance as well as self-reported health, we argue that this is unlikely to be driving our results. We find correlations of noise with health outcomes that are consistent with existing experimental and theoretical evidence, and not for others. Furthermore, given the subtlety of the relationship between noise and health, the low level of general awareness about its potential effects, and the high and uncertain costs of moving home, we argue that self-selection is also unlikely to explain the observed correlations.

Thus overall we find strong suggestive evidence that residential noise annoyance, especially neighbour noise, is significantly correlated with health. Our results indicate that noise annoyance is associated with increased likelihood of cardio-vascular disease through disturbing sleep, higher cholesterol levels, arthritis and other joint and bone disorders, and that loud neighbours is highly related with increased headaches. Street noise can also present problematic health effects, especially in combination with the poor air quality that nearby traffic can bring. The results also strongly suggest that observational studies of either residential street noise or air quality need to consider the contribution of both to health; in our analyses even when we control for observably poor quality air we still find an independent effect of noise for some health issues, such as disease of the joints and bones and fatigue.

The larger conclusion of this paper, however, is that much more research is needed. For all its ubiquity, residential noise pollution receives relatively little attention from policy-makers and regulators, due largely we suspect to the difficulty in "objectively" measuring the problem. It is hard to know whether acoustic retrofitting will be cost effective if we cannot estimate the true price of noise. This paper shows that there are reasonable alternative survey methods that rely on self-reporting of noise annoyance, and while concerns remain about possible endogeneity in the use of subjective data, we view this relatively low-cost study as a first step on the road to further research. The LISS CentER data used in this analysis was not designed *ex ante* to study noise pollution; a much more focused survey design could achieve much greater precision and address some of the lingering concerns about the accuracy of self-reported data and unobservable missing variables. As urbanization spreads across the world, residential noise pollution deserves much more academic and policy attention.

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Tables

Table 1: Summary statistics

Note: Continuous variables are sample period average. Dummy variables take the value 1 if the variable ***ever*** took the value 1 during the sample period.

Variable	Obs	Mean	St. Dev.	Min	Max
Neighbour Noise	5243	0.332	0.471	0	1
Street Noise	5243	0.195	0.397	0	1
Bad Air	5243	0.104	0.305	0	1
Health Level	5243	3.124	0.645	1	5
sleep disturbance	5243	0.297	0.457	0	1
cardio-vascular	5243	0.143	0.350	0	1
fatigue	5243	0.997	0.057	0	1
headache	5243	0.274	0.446	0	1
blood pressure	5243	0.231	0.421	0	1
cholesterol	5243	0.180	0.384	0	1
stroke	5243	0.024	0.154	0	1
joints & bones	5243	0.625	0.484	0	1
lung disease	5243	0.133	0.340	0	1
asthma	5243	0.056	0.229	0	1
diabetes	5243	0.072	0.259	0	1
dwelling small	5243	0.135	0.342	0	1
dwelling dark	5243	0.040	0.197	0	1
dwelling cold	5243	0.060	0.238	0	1
dwelling leaky	5243	0.039	0.192	0	1
dwelling damp	5243	0.082	0.274	0	1
dwelling rotten	5243	0.066	0.248	0	1
eversmoke	5243	0.655	0.475	0	1
drinkfish	5243	0.247	0.432	0	1
BMI	5243	25.64	4.32	11	50
age	5243	49.30	14.57	19	90
male	5243	0.510	0.500	0	1
primary education	5243	0.010	0.102	0	1
secondary education	5243	0.109	0.311	0	1
post-secondary educ	5243	0.525	0.499	0	1
terciary education	5243	0.106	0.308	0	1
married	5243	0.606	0.489	0	1
unemployed	5243	0.061	0.239	0	1
housewife	5243	0.345	0.475	0	1
student	5243	0.052	0.223	0	1
retired	5243	0.216	0.411	0	1
hh #kids	5243	0.809	1.062	0	6
hh income (€ /month)	5243	3017	5123	80	245573
hours	5243	32.35	13.02	0	100
religious	5243	0.454	0.498	0	1
crime	5243	0.163	0.369	0	1
urban neighbourhood	5243	0.426	0.495	0	1
rural neighbourhood	5243	0.156	0.363	0	1

Table 2: Self-reported level of health from 1 (poor) to 5 (excellent) and residential noise, OLS

variables	(1) Self-reported health level (1-5)	(2) standardized betas
Neighbour noise	-0.149***	-0.082
	(0.025)	
Street noise	-0.057*	-0.024
	(0.035)	
Bad air	-0.103**	-0.030
	(0.049)	
Dwelling small	-0.054	-0.019
	(0.041)	
Dwelling dark	-0.154**	-0.030
	(0.076)	
Dwelling cold	-0.068	-0.015
	(0.068)	
Dwelling leaky	-0.107	-0.017
	(0.084)	
Dwelling damp	-0.120**	-0.032
	(0.053)	
Dwelling rotten	-0.016	-0.004
	(0.060)	
eversmoke	-0.108***	-0.079
	(0.019)	
drinkfish	0.008	0.004
	(0.027)	
BMI	-0.027***	-0.178
	(0.002)	
age	-0.006	-0.127
	(0.005)	
agesq	-0.000	-0.062
	(0.000)	
male	0.068***	0.053
	(0.020)	
educ_1	0.139	0.017
	(0.158)	
educ_2	0.073**	0.032
	(0.035)	
educ_3	0.108***	0.082
	(0.021)	
educ_4	0.171***	0.078
	(0.037)	
married	-0.013	-0.010
	(0.022)	
unemployed	-0.088	-0.017
	(0.066)	
housewife	0.022	0.009
	(0.035)	
student	0.036	0.008
	(0.078)	
retired	0.101***	0.057
	(0.039)	
hh #kids	0.014	0.023

	(0.010)	
log(hh income)	0.144***	0.114
	(0.021)	
hours	0.001	0.012
	(0.001)	
religion	-0.012	-0.008
	(0.019)	
crime	-0.072*	-0.026
	(0.041)	
urban	0.029	0.019
	(0.022)	
rural	0.034	0.016
	(0.028)	
Constant	2.994***	
	(0.206)	
Observations	5,243	5,243
R-squared	0.145	0.145

Robust standard errors clustered by household in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3A: Odds Ratios for cross-sectional logistic regressions of residential noise on disease outcomes, all age groups

variables	(1) Cardio-vascular	(2) Cholesterol	(3) Blood pressure	(4) Asthma	(5) Lung disease
Neighbour noise	1.384***	1.048	1.052	1.146	1.490***
	(0.008)	(0.717)	(0.664)	(0.475)	(0.001)
Street noise	1.020	1.205	1.261	1.059	1.298*
	(0.906)	(0.232)	(0.114)	(0.816)	(0.095)
Bad air	1.177	1.188	1.113	0.725	1.567**
	(0.479)	(0.411)	(0.600)	(0.375)	(0.025)
Dwelling small	1.186	1.289	1.173	1.328	1.052
	(0.412)	(0.270)	(0.448)	(0.251)	(0.781)
Dwelling dark	0.924	1.528	1.872**	1.403	1.667*
	(0.821)	(0.222)	(0.031)	(0.434)	(0.083)
Dwelling cold	1.593	1.043	0.882	3.150***	1.256
	(0.122)	(0.905)	(0.672)	(0.001)	(0.419)
Dwelling leaky	1.372	0.852	0.890	0.250	1.029
	(0.451)	(0.735)	(0.794)	(0.173)	(0.943)
Dwelling damp	1.043	0.951	0.956	0.933	1.304
	(0.864)	(0.826)	(0.857)	(0.837)	(0.241)
Dwelling rotten	1.057	1.014	1.057	0.522	0.842
	(0.851)	(0.966)	(0.838)	(0.204)	(0.557)
eversmoke	1.176	1.366***	1.068	0.959	1.466***
	(0.103)	(0.001)	(0.452)	(0.757)	(0.000)
drinkfish	1.160	1.070	1.014	0.858	0.796*
	(0.215)	(0.541)	(0.900)	(0.487)	(0.092)
BMI	1.045***	1.069***	1.134***	1.051***	1.068***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
age	0.986	1.226***	1.196***	0.991	0.924***
	(0.540)	(0.000)	(0.000)	(0.770)	(0.000)
agesq	1.001**	0.999***	0.999***	1.000	1.001***
	(0.012)	(0.000)	(0.000)	(0.564)	(0.000)
male	1.244**	1.550***	1.053	0.684***	0.840*
	(0.036)	(0.000)	(0.572)	(0.008)	(0.083)
educ_1	0.512	1.346	1.296	0.416	1.032
	(0.303)	(0.549)	(0.610)	(0.505)	(0.954)
educ_2	1.057	1.057	1.016	0.976	1.186
	(0.733)	(0.714)	(0.912)	(0.920)	(0.287)
educ_3	0.885	0.751***	0.935	0.833	0.785**
	(0.217)	(0.002)	(0.440)	(0.231)	(0.018)
educ_4	0.768	0.716**	0.636***	1.029	0.746
	(0.151)	(0.046)	(0.005)	(0.905)	(0.117)
married	1.377***	1.248**	1.063	0.967	1.183
	(0.003)	(0.028)	(0.514)	(0.831)	(0.114)
unemployed	1.237	1.307	1.046	0.808	1.011
	(0.517)	(0.389)	(0.874)	(0.676)	(0.972)
housewife	1.147	1.149	1.270	0.888	0.950
	(0.443)	(0.402)	(0.110)	(0.617)	(0.760)
student	1.201	1.070	0.449	1.674	1.144
	(0.683)	(0.932)	(0.483)	(0.301)	(0.730)
retired	1.286	1.202	1.192	0.871	0.765
	(0.134)	(0.216)	(0.228)	(0.640)	(0.144)
hh #kids	0.954	0.919	0.905**	0.998	0.984
	(0.394)	(0.113)	(0.041)	(0.976)	(0.756)

log(hh income)	0.686***	0.820**	1.002	0.906	0.667***
	(0.000)	(0.031)	(0.984)	(0.447)	(0.000)
hours	1.001	0.998	1.002	0.997	1.001
	(0.876)	(0.477)	(0.581)	(0.567)	(0.856)
religion	1.160	1.199**	1.190**	1.124	1.037
	(0.123)	(0.042)	(0.036)	(0.413)	(0.708)
crime	1.324	1.060	0.931	1.314	1.484**
	(0.120)	(0.754)	(0.690)	(0.306)	(0.022)
urban	1.085	1.070	0.920	0.962	1.036
	(0.448)	(0.513)	(0.383)	(0.812)	(0.744)
rural	0.840	0.906	0.891	0.726	0.768*
	(0.251)	(0.467)	(0.378)	(0.175)	(0.088)
Constant	0.201	0.000***	0.000***	0.047**	1.427
	(0.118)	(0.000)	(0.000)	(0.024)	(0.706)
Observations	5,242	5,239	5,239	5,235	5,242
Pseudo R-squared	0.123	0.192	0.207	0.0278	0.0785

Robust p-values from standard errors clustered at the household level in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3B: Odds Ratios for cross-sectional logistic regressions of residential noise on disease outcomes, all age groups

variables	(6) Joints & Bones	(7) Diabetes	(8) Stroke	(9) Fatigue	(10) Headache
Neighbour noise	1.672***	0.843	0.903	3.784**	1.516***
	(0.000)	(0.359)	(0.767)	(0.034)	(0.000)
Street noise	1.387***	0.872	1.507	0.426	1.326**
	(0.007)	(0.560)	(0.256)	(0.201)	(0.021)
Bad air	1.402*	2.177***	0.270		1.109
	(0.063)	(0.004)	(0.101)		(0.568)
Dwelling small	1.714***	1.739*	0.520	0.378	0.915
	(0.000)	(0.053)	(0.319)	(0.341)	(0.539)
Dwelling dark	0.879	0.825	1.207		0.871
	(0.619)	(0.667)	(0.806)		(0.589)
Dwelling cold	0.909	0.751	0.519	1.118	1.055
	(0.684)	(0.569)	(0.576)	(0.944)	(0.818)
Dwelling leaky	1.349	0.642	1.146		0.897
	(0.394)	(0.590)	(0.904)		(0.729)
Dwelling damp	1.269	1.007	1.414	0.081***	1.846***
	(0.224)	(0.985)	(0.476)	(0.005)	(0.001)
Dwelling rotten	1.292	1.111	1.939	2.002	1.089
	(0.276)	(0.803)	(0.293)	(0.669)	(0.719)
eversmoke	1.325***	1.292*	1.459	1.238	1.028
	(0.000)	(0.068)	(0.206)	(0.644)	(0.703)
drinkfish	1.004	0.955	1.325	1.176	0.755**
	(0.970)	(0.785)	(0.329)	(0.819)	(0.018)
BMI	1.047***	1.147***	1.032	1.059	1.025***
	(0.000)	(0.000)	(0.181)	(0.228)	(0.001)
age	0.994	1.155***	1.156	0.972	0.979
	(0.752)	(0.000)	(0.133)	(0.786)	(0.302)
agesq	1.000*	0.999***	0.999	1.000	1.000
	(0.052)	(0.008)	(0.405)	(0.930)	(0.719)
male	0.662***	1.606***	0.985	0.577	0.397***
	(0.000)	(0.001)	(0.955)	(0.288)	(0.000)
educ_1	0.815	1.239	3.620		0.827
	(0.596)	(0.774)	(0.120)		(0.682)
educ_2	0.775**	1.495*	0.652		0.785*
	(0.039)	(0.054)	(0.350)		(0.072)
educ_3	0.862*	0.692***	0.711	0.623	0.753***
	(0.054)	(0.009)	(0.180)	(0.486)	(0.001)
educ_4	0.657***	0.774	0.246*		0.527***
	(0.000)	(0.314)	(0.064)		(0.000)
married	1.160**	1.346**	1.213	4.842**	1.154*
	(0.050)	(0.049)	(0.497)	(0.014)	(0.098)
unemployed	1.010	1.342	0.384	0.154**	1.466
	(0.965)	(0.518)	(0.439)	(0.015)	(0.109)
housewife	1.140	1.139	0.443	2.620	1.090
	(0.315)	(0.579)	(0.116)	(0.415)	(0.496)
student	1.300	2.835			0.830
	(0.316)	(0.219)			(0.487)
retired	0.725**	1.426*	0.579	0.499	0.702*
	(0.037)	(0.092)	(0.160)	(0.399)	(0.058)
hh #kids	0.986	0.907	0.929	1.306	1.054
	(0.682)	(0.256)	(0.689)	(0.402)	(0.148)
log(hh income)	0.844**	0.772*	0.564*	0.814	0.815**

	(0.014)	(0.063)	(0.060)	(0.730)	(0.012)
hours	0.998	0.993	1.006	1.026	0.998
	(0.444)	(0.148)	(0.492)	(0.336)	(0.495)
religion	0.985	1.108	0.871	0.459	1.111
	(0.828)	(0.431)	(0.578)	(0.171)	(0.167)
crime	0.999	1.186	1.470		1.580***
	(0.994)	(0.548)	(0.398)		(0.001)
urban	0.773***	0.958	0.830	1.910	1.051
	(0.001)	(0.776)	(0.494)	(0.237)	(0.564)
rural	0.948	1.003	0.392**	4.821	0.974
	(0.618)	(0.989)	(0.048)	(0.102)	(0.820)
Constant					
Observations	5,242	5,239	4,931	2,976	5,215
Pseudo R-squared	0.0644	0.131	0.120	0.154	0.0815

Robust p-values from standard errors clustered at the household level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4A: Odds Ratios for cross-sectional logistic regressions of residential noise on disease outcomes, by age groups

variables	(1) Cardio-vascular	(2) Cholesterol	(3) Blood pressure	(4) Asthma	(5) Lung disease
	Middle: Respondents Age 31-67 in 2007				
Neighbour noise	1.510***	1.113	1.024	1.016	1.411**
	(0.004)	(0.446)	(0.852)	(0.942)	(0.014)
Street noise	1.154	1.247	1.273	1.098	1.439**
	(0.458)	(0.202)	(0.132)	(0.753)	(0.047)
Bad air	1.189	1.076	1.178	0.686	1.491*
	(0.531)	(0.762)	(0.460)	(0.391)	(0.098)
Observations	3,853	3,850	3,850	3,817	3,853
Pseudo R-squared	0.100	0.144	0.155	0.0311	0.0654
	Young: Respondents Age 17-29 in 2007				
Neighbour noise	1.226	1.181	1.680	1.234	1.478
	(0.556)	(0.800)	(0.241)	(0.655)	(0.223)
Street noise	0.754	0.255	2.490	1.396	1.256
	(0.601)	(0.147)	(0.187)	(0.533)	(0.600)
Bad air	1.074	7.090**	5.400*	1.301	2.281
	(0.934)	(0.031)	(0.086)	(0.769)	(0.180)
Observations	914	864	782	932	935
Pseudo R-squared	0.0677	0.195	0.216	0.104	0.104
	Old: Respondents Age 67+ in 2007				
Neighbour noise	0.932	0.655	1.151	4.986**	2.401*
	(0.871)	(0.350)	(0.756)	(0.043)	(0.060)
Street noise	0.781	1.343	1.247	0.257	0.823
	(0.574)	(0.494)	(0.604)	(0.427)	(0.690)
Bad air	1.146	1.605	0.528	0.725	1.387
	(0.782)	(0.342)	(0.259)	(0.748)	(0.558)
Observations	453	451	451	393	451
Pseudo R-squared	0.0777	0.0530	0.0750	0.138	0.144

Robust p-values from standard errors clustered by household in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Also included in regression but not displayed: dwelling characteristics, neighbourhood characteristics, smoking and drinking habits, BMI, age, gender, education, marital status, labour market status, hours worked, household income, number of children, indicator of religious status.

Table 4B: Odds Ratios for cross-sectional logistic regressions of residential noise on disease outcomes, by age groups

variables	(6) Joints & Bones	(7) Diabetes	(8) Stroke	(9) Fatigue	(10) Headache
	Middle: Respondents Age 30-66 in 2007				
Neighbour noise	1.939***	0.850	0.810	6.294***	1.500***
	(0.000)	(0.435)	(0.616)	(0.004)	(0.000)
Street noise	1.416**	0.926	1.851	0.305*	1.517***
	(0.018)	(0.773)	(0.134)	(0.082)	(0.004)
Bad air	1.304	1.885*	0.233		1.077
	(0.215)	(0.051)	(0.174)		(0.732)
Observations	3,853	3,850	3,799	2,311	3,832
Pseudo R-squared	0.0607	0.165	0.121	0.198	0.0813
	Young: Respondents Age 17-29 in 2007				
Neighbour noise	1.173	1.003			1.432*
	(0.412)	(0.998)			(0.079)
Street noise	1.108	1.924			1.027
	(0.679)	(0.503)			(0.923)
Bad air	1.481	1.553			1.191
	(0.364)	(0.714)			(0.703)
Observations	935	475			930
Pseudo R-squared	0.0469	0.269			0.0907
	Old: Respondents Age 67+ in 2007				
Neighbour noise	1.827	0.760	2.157		3.181**
	(0.365)	(0.602)	(0.362)		(0.019)
Street noise	4.746**	0.512	0.551		0.921
	(0.037)	(0.248)	(0.599)		(0.878)
Bad air	1.455	2.796*	0.455		1.207
	(0.628)	(0.074)	(0.547)		(0.754)
Observations	437	453	396		450
Pseudo R-squared	0.105	0.0680	0.0902		0.114

Robust p-values from standard errors clustered by household in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Also included in regression but not displayed: dwelling characteristics, neighbourhood characteristics, smoking and drinking habits, BMI, age, gender, education, marital status, labour market status, hours worked, household income, number of children, indicator of religious status.

Table 5A: Odds Ratios for cross-sectional logistic regressions of residential noise and sleep disturbance on disease outcomes, respondents age 30-66 in 2007

variables	(1) Sleep disturbance	(2) Cardio- vascular	(3) Cholesterol	(4) Blood pressure	(5) Asthma	(6) Lung disease
Neighbour noise	1.782***	1.377**	1.032	0.942	0.955	1.275*
	(0.000)	(0.028)	(0.825)	(0.650)	(0.834)	(0.091)
Street noise	1.602***	1.070	1.188	1.199	1.051	1.305
	(0.001)	(0.728)	(0.327)	(0.260)	(0.870)	(0.155)
Bad air	1.121	1.132	1.050	1.166	0.688	1.468
	(0.578)	(0.652)	(0.843)	(0.491)	(0.399)	(0.114)
Sleep disturbance		2.558***	1.748***	2.147***	1.706***	3.024***
		(0.000)	(0.000)	(0.000)	(0.005)	(0.000)
Observations	3,832	3,832	3,829	3,829	3,796	3,832
Pseudo R-squared	0.0726	0.115	0.149	0.165	0.0352	0.0886

Robust p-values from standard errors clustered by household in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Also included in regression but not displayed: dwelling characteristics, neighbourhood characteristics, smoking and drinking habits, BMI, age, gender, education, marital status, labour market status, hours worked, household income, number of children, indicator of religious status.

Table 5B: Odds Ratios for cross-sectional logistic regressions of residential noise and sleep disturbance on disease outcomes, respondents age 30-66 in 2007

variables	(7) Joints & Bones	(8) Diabetes	(9) Stroke	(10) Fatigue	(11) Headache
Neighbour noise	1.845***	0.801	0.739	6.143***	1.355***
	(0.000)	(0.297)	(0.472)	(0.003)	(0.007)
Street noise	1.306*	0.878	1.742	0.300*	1.391**
	(0.073)	(0.627)	(0.178)	(0.064)	(0.030)
Bad air	1.354	1.779*	0.214		1.076
	(0.168)	(0.078)	(0.156)		(0.744)
Sleep disturbance	2.788***	1.754***	2.146**	3.307	3.735***
	(0.000)	(0.002)	(0.016)	(0.387)	(0.000)
Observations	3,832	3,829	3,779	2,296	3,832
Pseudo R-squared	0.0752	0.169	0.129	0.207	0.114

Robust p-values from standard errors clustered by household in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Also included in regression but not displayed: dwelling characteristics, neighbourhood characteristics, smoking and drinking habits, BMI, age, gender, education, marital status, labour market status, hours worked, household income, number of children, indicator of religious status.

Table 6: Panel fixed effects estimates of the effects of noise and sleep disturbance on self-reported health levels, all age groups

Variables: (defined over previous 3 years inclusive)	(1) Self-reported health level (1-5)	(2) Self-reported health level (1-5)
Neighbour noise	0.008	0.010
	(0.688)	(0.641)
Street noise	-0.058**	-0.059**
	(0.018)	(0.017)
Bad air	-0.054*	-0.058*
	(0.066)	(0.050)
Sleep disturbance		-0.134***
		(0.000)
Dwelling small	0.031	0.032
	(0.371)	(0.361)
Dwelling dark	0.095*	0.092*
	(0.061)	(0.067)
Dwelling cold	-0.018	-0.011
	(0.676)	(0.795)
Dwelling leaky	-0.128**	-0.121**
	(0.019)	(0.028)
Dwelling damp	-0.012	-0.013
	(0.746)	(0.730)
Dwelling rotten	-0.027	-0.021
	(0.532)	(0.622)
Unemployed	0.014	0.021
	(0.724)	(0.583)
Retired	-0.012	-0.010
	(0.717)	(0.767)
Student	-0.124**	-0.118*
	(0.042)	(0.055)
Married	0.017	0.022
	(0.697)	(0.603)
Constant	3.088***	3.116***
	(0.000)	(0.000)
Fixed Effects	y	y
R-squared	0.003	0.007
Observations	16,292	16,207
Individuals	5,564	5,527

Robust p-values from standard errors clustered by individual in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Odds Ratios from Conditional Fixed Effects Logistic Regression of the effects of noise on specific health outcomes, all age groups

Variables: (defined over previous 3 years inclusive)	(1) Cardio-vascular	(2) Cholesterol	(3) Blood pressure	(4) Lung disease	(5) Joints &Bones	(6) Fatigue	(7) Headache
Neighbour	1.736*	2.882*	1.564	0.367*	2.043**	1.105	6.852**
Noise	(0.084)	(0.061)	(0.386)	(0.070)	(0.028)	(0.351)	(0.016)
Street Noise	1.036	1.132	1.444	1.595	1.872*	1.220	2.305
	(0.930)	(0.850)	(0.480)	(0.555)	(0.088)	(0.139)	(0.172)
Bad Air	2.110*	1.201	8.939**	2.774	3.565**	0.795	1.239
	(0.059)	(0.767)	(0.039)	(0.132)	(0.021)	(0.152)	(0.716)
Dwelling	1.030		2.332	1.994	1.381	0.836	3.509
Small	(0.954)		(0.467)	(0.391)	(0.497)	(0.269)	(0.100)
Dwelling	0.326	2.726	1.639	1.152	5.069	1.117	3.427
Dark	(0.283)	(0.413)	(0.658)	(0.928)	(0.145)	(0.720)	(0.293)
Dwelling	0.137*	1.395		0.452	0.592	1.039	2.817
Cold	(0.093)	(0.805)		(0.519)	(0.429)	(0.871)	(0.339)
Dwelling	0.078***	0.447		0.814	1.364	2.259***	
Leaky	(0.006)	(0.589)		(0.855)	(0.528)	(0.002)	
Dwelling	1.165	1.866		2.604	0.509	1.514**	1.135
Damp	(0.821)	(0.548)		(0.252)	(0.316)	(0.044)	(0.837)
Dwelling	0.814	0.070		1.840	3.321*	1.132	0.949
Rotten	(0.740)	(0.135)		(0.527)	(0.088)	(0.553)	(0.957)
Unemployed	0.999	2.971	12.333**	0.530	2.554	0.842	1.233
	(0.999)	(0.228)	(0.019)	(0.468)	(0.142)	(0.444)	(0.845)
Retired	2.953**	1.260	3.987	1.219	3.117**	4.622***	0.662
	(0.026)	(0.721)	(0.211)	(0.874)	(0.035)	(0.000)	(0.775)
Student	0.501			0.000	0.322	0.054***	
	(0.524)			(0.992)	(0.241)	(0.000)	
Married	1.180	0.992	0.824	0.694	0.542	0.557**	0.470
	(0.845)	(0.994)	(0.820)	(0.543)	(0.288)	(0.012)	(0.328)
Fixed Effects	y	y	y	y	y	y	y
Observations	1,395	588	680	496	1,356	10,812	564
Individuals	351	214	247	185	532	2,914	214

p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8A: Odds Ratios from Conditional Fixed Effects Logistic Regression of the effects of noise and sleep disturbance on specific health outcomes, all age groups

Variables: (defined over previous 3 years inclusive)	(1) Sleep Disturbance	(2) Cardio-vascular	(3) Cholesterol	(4) Blood Pressure
Neighbour Noise	2.622***	1.663	3.018*	1.610
	(0.009)	(0.116)	(0.056)	(0.362)
Street Noise	1.125	1.111	1.098	1.445
	(0.761)	(0.791)	(0.888)	(0.479)
Bad Air	0.460*	2.129*	1.081	9.610**
	(0.072)	(0.057)	(0.901)	(0.036)
Sleep Disturbance		2.532***	3.523**	1.860
		(0.001)	(0.021)	(0.188)
Fixed Effects	y	y	y	y
Observations	1,068	1,386	584	678
Individuals	381	349	213	247

p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Also included in regression but not displayed: dwelling characteristics, marital status, and labour market status.

Table 8B: Odds Ratios from Conditional Fixed Effects Logistic Regression of the effects of noise and sleep disturbance on specific health outcomes

Variables: (defined over previous 3 years inclusive)	(5) Lung disease	(6) Joints & Bones	(7) Fatigue	(8) Headache
Neighbour Noise	0.502	1.989**	1.108	7.304**
	(0.243)	(0.036)	(0.342)	(0.021)
Street Noise	1.265	1.882*	1.213	2.238
	(0.775)	(0.088)	(0.151)	(0.192)
Bad Air	2.408	3.853**	0.817	1.056
	(0.231)	(0.015)	(0.207)	(0.927)
Sleep Disturbance	8.849***	1.599	1.268*	5.104***
	(0.000)	(0.126)	(0.077)	(0.000)
Fixed Effects	y	y	y	y
Observations	496	1,344	10,801	564
Individuals	185	528	2,914	214

p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Also included in regression but not displayed: dwelling characteristics, marital status, and labour market status.