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AIRCRAFT NOISE, HEALTH, AND RESIDENTIAL SORTING: EVIDENCE FROM TWO QUASI-EXPERIMENTS

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SUMMARY

We explore two unexpected changes in flight regulations to estimate the causal effect of aircraft noise on health. Detailed measures of noise are linked with longitudinal data on individual health outcomes based on the exact address information. Controlling for individual heterogeneity and spatial sorting into different neighborhoods, we find that aircraft noise significantly increases sleeping problems and headaches. Models that do not control for such heterogeneity and sorting substantially underestimate the negative health effects, which suggests that individuals self-select into residence based on their unobserved sensitivity to noise. Our study demonstrates that the combination of quasi-experimental variation and panel data is very powerful for identifying causal effects in epidemiological field studies. Copyright © 2013 John Wiley & Sons, Ltd.

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KEY WORDS: Health; noise pollution; residential sorting; fixed effects; quasi-experiments

1. INTRODUCTION

State regulations against noise pollution are a recurring theme on the public policy agenda in many countries. On the one hand, such regulations are enacted to reduce the risk of long-term health damage from noise exposure. On the other hand, any attempt to lower the existent levels of noise will inevitably generate costs that have to be internalized. A rich body of cross-sectional research (e.g. Black *et al*., 2007; Stansfeld *et al*., 2005; Huss *et al*., 2010) has analyzed the relationship between aircraft noise and health. However, identifying the *causal* effect of noise on health is very difficult empirically, and the findings from the previous literature have not been conclusive in that respect.

The main reason why cross-sectional evidence cannot be given a causal interpretation is that individuals are not randomly exposed to noise. First, noisy regions differ from quiet ones in unobservable but health-relevant aspects other than noise (e.g. the quality of the neighborhood). Second, people may self-select into locations based on their preferences for quietness, their pre-existing health conditions, and their ability to afford to live in a quiet neighborhood. All else equal, spatial sorting will lead noise-sensitive people to live in quiet areas, whereas noise-insensitive and resistant people will live in noisier and often cheaper neighborhoods (Van Wee, 2009). If this non-random selection into residence is not accounted for in the empirical model, then any cross-sectional evidence on the relationship between noise and health is unlikely to have a causal interpretation.

This paper aims at estimating the causal effect of aircraft noise on health using a quasi-experimental identification strategy combined with panel data on health outcomes. We estimate fixed effects models that

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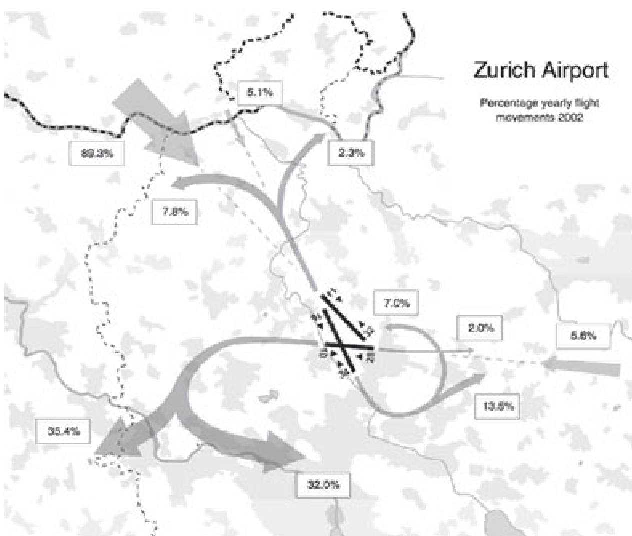
control for time-constant confounders, including both unobserved individual heterogeneity and spatial sorting into different neighborhoods related to health. Although fixed effects models have been used to examine the impact of air pollution on health (e.g. Neidell, 2004; Coneus and Spiess, 2012), this approach has not been used so far to study the effects of aircraft noise. Two possible explanations for this are that, first, aircraft noise does not vary much over time (in particular on a year-to-year basis), and second, if such variation occurs, then it may not be exogenous but related to the relocation of individuals (often involving health-relevant choices like a change of job or a new personal situation). For this reason, we examine the impact of two large exogenous shocks to aircraft noise on the health of individuals living in the same residence over the study period. Combined with individual fixed effects, this approach can identify the causal impact of aircraft noise.[1]

Exogenous variation in aircraft noise is generated by two unexpected changes in flight regulations at Zurich airport. Being Switzerland's largest gateway, it operates around 270,000 flights every year distributed on three different runways: directions north/south, northwest/southeast, and east/west (see Figure 1). In summer 2000, the east/west runway had to be closed for 2 months because of the construction of a new terminal. During this period, aircraft used the north/south runway instead of the east/west one. The second large-scale change happened in 2003. Because the airport is located relatively close to the Swiss-German border (dark dashed line in Figure 1), the German government issued a binding decree in April 2003 that prohibited landings over their territory in the early morning and in the late evening as a protective measure against noise pollution. After a temporary redistribution of incoming flights to the east, the *Swiss Federal Office of Civil Aviation* changed the flight regulations to allow for landings from the south, which had been previously prohibited. After this



Notes: Percentage occupancy of landing and takeoff routes in 2002. Light grey are settlement areas. Thick dashed line marks Swiss-German border. Thin dashed line marks cantonal border. North/south runway 16/34, northwest/southeast runway 14/32, east/west runway 10/28.

Source: Flughafen Zürich (2011, p. 50) adapted to 2002 figures.

Figure 1. Zurich airport and flight paths in 2002

[1]In related areas, for example, environmental economics, quasi-experiments have already become a popular tool to identify causal effects (Parmeter and Pope, 2009; Greenstone and Gayer, 2009; Boes and Nüesch, 2011). See also DiNardo (2008) for a critical assessment of quasi-experiments in the social sciences in general.

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change, which began being enforced in October 2003, early morning aircraft were redirected to land from the south and late evening aircraft from the east (rather than from the north directions).

We estimate the effect of aircraft noise on health using self-reported health data drawn from the *Swiss Household Panel* (SHP), a large and representative panel survey of the Swiss population fielded on an annual basis. We examine subjective health outcomes from specific domains that are likely to be impacted by aircraft noise, including sleeping quality, weakness/weariness, and headaches, and measures of general health including overall health status, the number of doctor consultations, and the number of days affected by health problems. We link each individual in the SHP to detailed continuous and longitudinal aircraft noise data provided by the *Swiss Federal Laboratories for Materials Science and Technology* (EMPA) based on the spatial coordinates of their home address.

Our analyses indicate that cross-sectional studies underestimate the negative effects of aircraft noise on health. Whereas the association between aircraft noise and health is insignificant and small in cross-sectional specifications, once we include individual fixed effects, we find that aircraft noise significantly increases sleeping problems and headaches. One likely explanation why the cross-sectional specifications underestimate the effect of aircraft noise on health is that individuals sort into neighborhoods based on their vulnerability to noise. As noise-sensitive people tend to self-select into quiet regions, the population there is negatively selected with respect to pre-existing health inputs, and studies that do not control for this type of sorting will underestimate the causal effect of noise on health. Individual fixed effects control for a person's noise sensitivity, defined as a *stable* personality trait covering attitudes toward noise and influencing one's reaction to noise, independent of the actual noise level (Nijland *et al*., 2007).

Although residential sorting can explain the difference in results between the cross-sectional and the fixed effects models, we cannot rule out habituation as a further possible explanation. Individuals tend to get used to noise over time (Griefahn, 2002). If this adjustment process occurs slowly, the underestimation of noise effects due to habituation will be smaller in fixed effects models than in cross-sectional models. Avoidance behavior could additionally downward bias the estimated coefficients (Neidell, 2009). Individuals living in noisy regions are likely to take actions to reduce their noise exposure, such as sleeping with closed windows and having soundproof windows installed. However, avoidance behavior should equally impact both the cross-sectional and fixed effects estimates because people can promptly change their behaviors when noise exposure changes.

Before we lay out the details of the analysis, we will briefly review the literature on the effects of noise on health. In Section 3, we describe the two data sources and their linkage. Section 4 presents the identification strategy and the results. Section 5 concludes.

2. RELATED LITERATURE

The health effects of noise emerge as a direct consequence of exposure or indirectly through subjective reactions like annoyance (Job, 1996). Whereas the exposure to high levels of noise (e.g. above 75 dB (A), A-weighted decibels) for extended durations can cause hearing loss (Alberti, 1992), exposure to moderate levels of noise is thought to affect health mainly indirectly via perceived stress (Babisch *et al*., 2003). This component in turn is largely determined by the emotional and cognitive evaluation of the stressor, in our case aircraft noise. Thus, the potential health effects of aircraft noise are thought to be mainly induced by annoyance or some other form of negative appraisal. Noise-sensitive individuals experience more stress when exposed to noise than noise-insensitive individuals who are better able to cope with the noise stimuli (Black *et al*., 2007; Fyhri and Klaboe, 2009).

Previous laboratory studies have documented the adverse effects of nocturnal noise on subjective sleep quality (Elmenhorst *et al*., 2010) and on blood pressure (Haralabidis *et al*., 2008). The key advantage of lab experiments is that they enable the researcher to randomly manipulate noise exposure in a well-controlled environment, which leads to precise estimates of the causal impact of noise on health. On the downside, the long-term effects of noise cannot be tested either because of time and/or money constraints or because ethics

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committees would not approve studies that could cause a major health deterioration. A second limitation is that laboratory findings are unlikely to have external validity for the impact of noise in everyday living situations. In the home environment, people become accustomed to noise over time, also called habituation effect (Griefahn, 2002), and tend to develop coping mechanisms (like sleeping with closed windows) that reduce the perceived noise nuisance. As study participants are likely to pay more attention to noise in the lab, the measured health effects tend to be stronger than in the field (Pirrera *et al*., 2010). To address the limitations of lab studies, additional field studies on the noise-health relationship are required.

Epidemiological field studies have relied on cross-sectional samples so far. For example, Black *et al*. (2007), Eriksson *et al*. (2007), and Jarup *et al*. (2008) found significantly positive correlations between aircraft noise and hypertension. Franssen *et al*. (2004) showed that aircraft noise significantly deteriorated self-reported health and increased the use of non-prescribed sleep medication. Stansfeld *et al*. (2005) found a significant detrimental effect of aircraft noise on cognitive performance (reading comprehension, recognition) of children but no significant effect on health. Huss *et al*. (2010) found an insignificant relationship between aircraft noise and mortality because of strokes, cancer, and circulatory disease and a marginally significant relationship between aircraft noise and mortality caused by acute myocardial infarction.

In cross-sectional studies, it is important to consider the possibility that individuals living in areas highly exposed to noise may have poor health because of the existence of other factors, such as their socioeconomic status or air pollution in the neighborhood (Job, 1996). Most cross-sectional studies include control variables for a person's sex, age, and educational level. Several studies also take a person's socioeconomic status (e.g. income, employment status) or lifestyle factors (e.g. smoking, alcohol consumption, intake of fruits and vegetables, BMI) into account. Huss *et al*. (2010) shows that the proportion of persons with tertiary education declines with increasing aircraft noise, whereas the proportion of unemployed, people living in old buildings, and foreign nationals increases.

Although this evidence suggests that the population in quiet regions is positively selected in terms of health inputs, the direction of selection is not unequivocally determined. It is quite likely that there is negative selection based on noise sensitivity, with noise-sensitive people tending to settle in quiet regions and noise-insensitive people tending to self-select into noisier and often cheaper regions (e.g. Van Wee, 2009). Such residential sorting will bias the effect of noise on health if it is related to both factors. Previous studies have documented that a person's noise sensitivity is positively associated with components of a pre-morbid personality (e.g. negative affectivity, neuroticism, critical tendency), psychiatric disorders, feelings of exhaustion (weariness, tiredness, and faintness), pain in the limbs, headache, heart problems (heart consciousness, chest pain), and sleeping problems (see Fyhri and Klaboe, 2009, for a review of this literature). Thus, there is ample evidence that noise sensitivity is a confounding factor in the noise-health relationship.

Although some studies (e.g. Babisch *et al*., 2005; Kishikawa *et al*., 2009) try to use specific questions to measure individual noise sensitivity (e.g. Weinstein's noise sensitivity scale), we assume that noise sensitivity is time invariant and can be captured by individual fixed effects in a panel data model. Such a strategy is reasonable, given the evidence from human-biological and acoustic research. For example, a twin study of Heinonen-Guzejev *et al*. (2007) shows that noise sensitivity is largely genetically determined, and the lab experiment of Ellermeier *et al*. (2001) suggests that varying levels of noise exposure do not affect a person's self-reported noise sensitivity. Unfortunately, we do not have data that would allow us to construct a noise sensitivity measure, and therefore, we cannot compare the two approaches here.

3. DATA AND INSTITUTIONAL BACKGROUND

We use two different data sources to construct our linked health-noise dataset. The data on aircraft noise exposure is provided by the *Swiss Laboratories for Materials Science and Technology* (EMPA). The information on health outcomes is drawn from a large and nationally representative panel survey, the *Swiss Household Panel* (SHP). We will consider the two datasets in turn and then discuss how we linked them.

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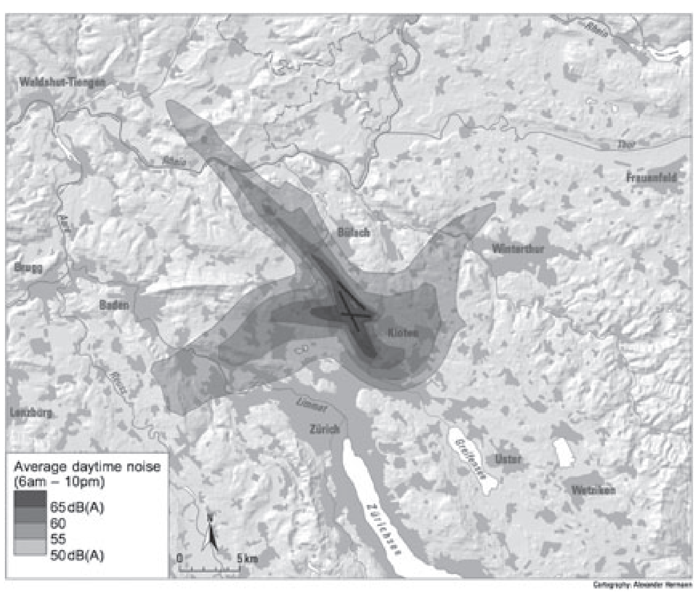
3.1. Aircraft noise data

We employ model-based continuous noise data provided by the *Swiss Federal Laboratories for Material Science and Technology* (EMPA). The EMPA calculates annual data on aircraft noise exposure based on effective radar flight track information, aircraft noise profiles, and environmental characteristics such as terrain or prevalent winds with a resolution of 250 × 250 m and then interpolates noise exposure to a 100 × 100–m grid (see Krebs *et al*. (2010) for additional details about the EMPA aircraft noise model and Thomann (2007) for information on the model precision). In our analyses, we use $L_{eq}^{d}(16)$ and $L_{eq}^{n}(1)$ as noise measures. L_{eq} is a metric that indicates the corresponding steady sound level for a given time interval that would produce the same energy as the actual time-varying noise intensity. $L_{eq}^{d}(16)$ is the average noise intensity for the 16-hour interval between 6 AM and 10 PM, whereas $L_{eq}^{n}(1)$ is the noise intensity for the 1-hour interval between 10 and 11 PM. The units of measurement are A-weighted decibels, abbreviated by dB(A). The annual noise measures are available for the years 1999 to 2005. Figure 2 shows the distribution of daytime noise $L_{eq}^{d}(16)$ in 2002. The dark regions correspond to the highest levels of average noise exposure. The areas directly surrounding the airport and in direction of the three runways are most heavily exposed to aircraft noise.

3.2. Health data

The information on aircraft noise is merged into the *Swiss Household Panel* (SHP). The SHP is an annual longitudinal survey of the Swiss population that was first fielded in 1999 and collects data from around 5000 households and all their members aged 14 years and older. The data are collected using computer-assisted telephone interviews (CATIs) held from September to February each wave. For detailed information about the SHP, its study design, sampling frame, and data quality, see Voorpostel *et al*. (2010). For this study, we focus on individuals who reside in the canton of Zurich as this is the relevant area for evaluating the effects of aircraft noise on health around the Zurich airport. The SHP captures individual health in a variety of questions that concern both specific and general health outcomes.



Source: EMPA, own calculations. Daytime noise $L_{eq}^{d}(16)$ for the 16 hour interval 6 am to 10 pm in 2002.

Figure 2. Daytime aircraft noise exposure in 2002

3.3. Linking aircraft noise and individual health

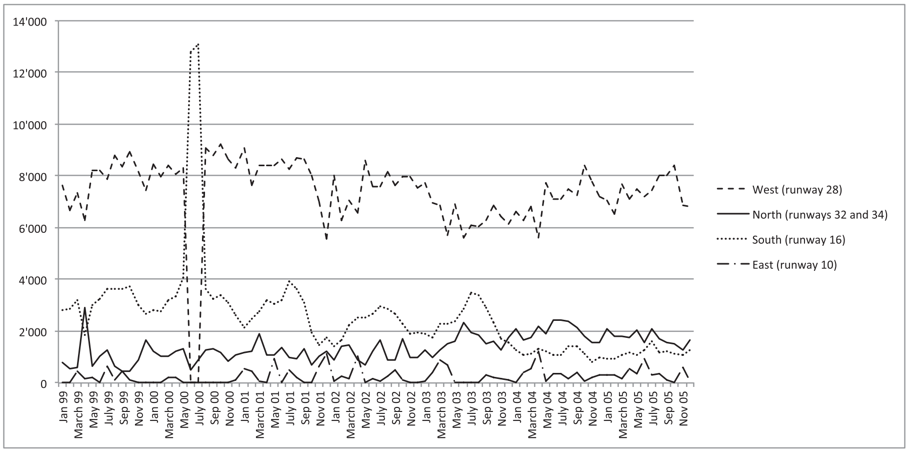
The public use version of the SHP indicates a household's canton of residence as the lowest level of geographic aggregation. We gratefully acknowledge the provision of exact household addresses (community, zip code, street name, and street number) by the *Swiss Centre of Expertise in the Social Sciences*, which runs the SHP, after signing a special data confidentiality agreement. We transformed this information into Swiss grid coordinates using the Web page http://tools.retorte.ch/map/. For only 4.5 per cent of the cases, coordinates could not be determined exactly based on the street name and number, either because of misspelling or because the Web page did not program the respective address into the system. In these rare cases, we used the coordinates of the population-weighted center of gravity of the address' zip code, provided by the geographical information system (GIS) software of *MicroGIS*.

We then linked each individual in the SHP to the appropriate aircraft noise data based on the point in the 100 $\times$ 100–m grid that is nearest to the exact location of the household. Given the constraints of each data source, this is the best possible match and should provide a very accurate picture of aircraft noise exposure at each individual's place of residence. This is important as environmental noise tends to be a local phenomenon and imprecise matching inevitably leads to measurement errors and reduced statistical power.

3.4. Flight regime changes

We exploit two changes in flight regulations at Zurich airport as source of exogenous variation in aircraft noise exposure. Zurich airport has three different runways, and thus, aircraft could in principle start and land in six directions. Figure 1 shows the percentage occupancy of landing and takeoff routes in 2002. Aircraft generally landed from the northwest on runway 14 and started in direction west on runway 28. Less frequently, runway 16 was used for takeoffs and landings. Flight regulations determine that aircraft are redirected to land from the east on runway 28 and start in direction north from runway 32 in case of strong west wind. In case of strong east wind, aircraft have to start on runway 10 in direction east.

The first change in flight regulations happened during summer 2000. The runway 10/28 had to be closed from May 29 to July 31, 2000 due to the construction of a new terminal (Midfield Dock E). Instead of starting to the west, aircraft had to be redirected to start in direction south on runway 16. Figure 3 shows the monthly number of departures on the basis of airport operation time, that is, from 6 am to 12 am, separately for each



Source: Flughafen Zürich AG, own calculations.

Figure 3. Monthly number of departures over the whole day

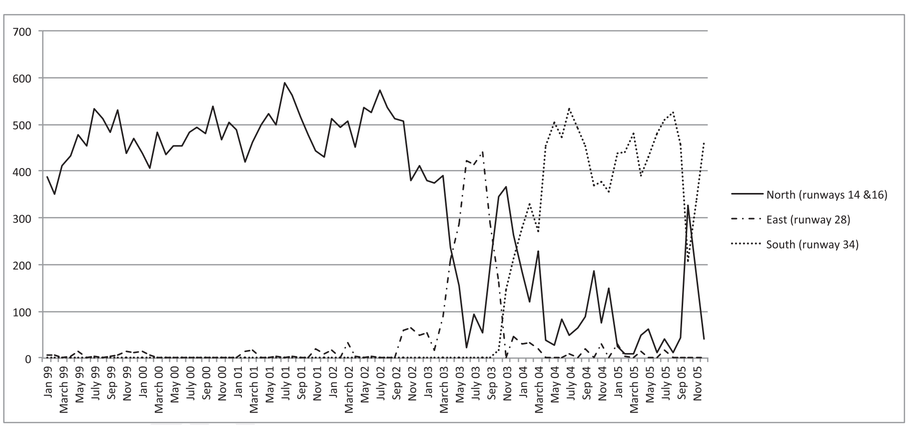
runway. We observe that the number of west departures dropped to zero and the number of south departures tripled in June and July 2000 due to the closure of runway 10/28.

The second important change happened in 2003 and primarily affected landings. Because Zurich airport is located close to the Swiss-German border (dark dashed line in Figure 1), the German government issued a binding decree in April 2003 that prohibited landings over German territory in the early morning (6 to 7 AM on weekdays and 6 to 9 AM on weekends) and late evening (9 PM to 12 AM on weekdays and 8 PM to 12 AM on weekends) as a protective measure against noise pollution. As a result, landings had to be redirected to runway 28 (from the east) because at that time the flight regulations did not allow any other direction. On 23 June 2003 the *Federal Office of Civil Aviation* decided to permit landings from the south on runway 34, starting from 30 October 2003. The new flight regulation (which has not been changed since) states that aircraft landing in the early morning hours approach from the south, and aircraft landing in the late evening hours approach from the east. Exceptions are only allowed in case of strong wind or fog or in the case of emergency flights (Flughafen Zürich, 2012).

Figure 4 illustrates the monthly number of landings in the early morning by flight direction. Before 2003, landings in the early morning were operated from the north, between April and October 2003 mainly from the east, and thereafter mainly from the south. The temporary increase of landings from the north in October 2005 was caused by the test phase of a new flight path from the northwest over Swiss territory. As the new flight path had to be carried out by a visual approach instead of using the otherwise prevailing instrument landing system, it was denied for safety reasons by the *Federal Office of Civil Aviation*.

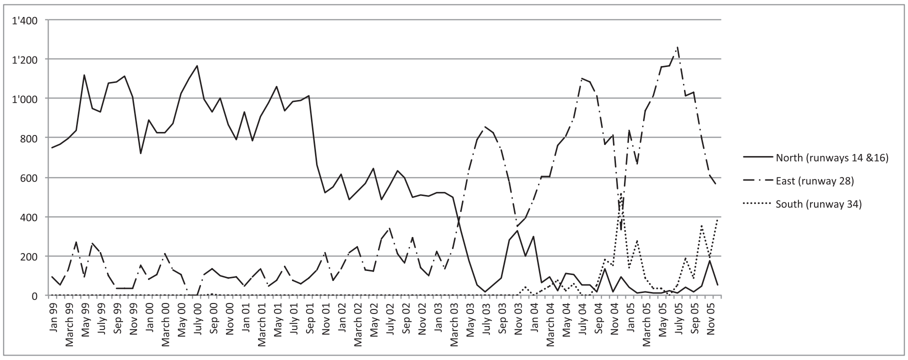
A decrease of landings from the north can also be observed in the late evening (Figure 5). After April 2003, landing aircraft between 9 PM and 12 AM were redirected to land from the east instead of the north. The temporary reductions of late landings from the east in winter can be explained by weather conditions and the corresponding safety regulations. The weather around the airport is often foggy then, and the flight regulations prescribe that landing aircraft have to approach from the south when visibility is less than 4300 m but more than 750 m. If visibility is less than 750 m, landing aircraft has to approach from the north (Flughafen Zürich, 2012).

The two flight regime changes substantially altered aircraft noise around the airport. Although the noise pollution in the north was generally reduced (in some areas by more than 6 dB(A) according to the daytime and nighttime measures), the region in the southeast of the airport was affected the most by the change in flight regulations (in some areas noise pollution increased by more than 9 dB(A) average sound level). It should be noted that the noise increases in the south in 2000 were caused by departing aircraft in this direction, whereas the increases observed in 2003 were caused by landing aircraft from the south.



Source: Flughafen Zürich AG, own calculations.

Figure 4. Monthly number of landings from 6 AM to 7 AM



Source: Flughafen Zürich AG, own calculations.

Figure 5. Monthly number of landings from 9 PM to 12 AM

4. HOW DOES AIRCRAFT NOISE AFFECT INDIVIDUAL HEALTH?

4.1. Identification strategy

The main contribution of this paper is to provide new and compelling evidence on the causal effect of aircraft noise on health. We identify this effect using the following model framework

$$H_{it} = f(N_{it}, X_{it}, \delta_t, \alpha_i, \varepsilon_{it}) \tag{1}$$

where H_{it} denotes health of individual i at time t, and N_{it} denotes exposure to aircraft noise. X_{it} is a vector of observed background variables, and δ_t are year fixed effects. α_i summarizes all time-constant and ε_{it} the remaining time-varying unobserved characteristics affecting health. The function $f(\cdot)$ translates health inputs into outputs and will be a linear function in our main specification.

To provide a broad picture of the possible effects of aircraft noise on health, we examine the impact on various health outcomes, including general and specific domains. Specific health outcomes are considered by using three indicators for regular suffers from *sleeping problems*, *headaches*, and *weakness/weariness*.[2] For a more general health assessment, we examine the response to a self-rated assessment of how the respondent currently feels (on a five-point scale). We constructed a binary indicator for *bad health status* from this question that is equal to 1 if the respondent states feeling so-so, not very well, or not well at all and equal to zero otherwise (which corresponds to feeling well or very well). In addition, general health impacts are measured by the *number of days affected by health problems* (in terms of carrying out usual activity at work or in the household) and the *number of doctor consultations* in the previous 12 months. The number of doctor consultations is also examined to provide a more objective evaluation of general health.

We expect to find stronger effects of aircraft noise on the specific noise-related outcomes like sleeping problems and headaches. The effects on general health or the number of doctor visits are likely to be weaker and possibly moderated by the specific domains. When measuring exposure to aircraft noise, we distinguish between daytime noise (6 AM to 10 PM) and nighttime noise (10 to 11 PM). This is the noise information contained in the EMPA data. On the one hand, we expect daytime noise to have stronger effects on health because it covers a longer time frame. On the other hand, the nighttime noise measure captures a more sensitive

[2]The three indicators are based on questions of the type ‘Over the last year, have you suffered at least once a month from any of the following disorders or health problems? (yes/no)’. The wording has changed in the 2004 wave to ‘During the last 4 weeks, have you suffered from any of the following disorders or health problems? (not at all, somewhat, very much)’. We use a consistent yes/no coding (regular sleeping problems before 2004 and very much or somewhat sleeping problems in 2004 and 2005) and accommodate changes in answer behavior by adding year dummies to our models.

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period when most people go to bed and hence when noise is expected to be particularly disturbing with regard to sleeping problems and other health outcomes.

The vector of control variables X_{it} includes log household income, an indicator whether the respondent changed job in the last year, the number of kids, and marital status (all time-varying), plus gender, age, education, and an indicator for Swiss nationality (the latter all time-constant or collinear with individual and time fixed effects). For comparability reasons, we require non-missing information on all covariates, including the job and moving history. Year fixed effects (δ_t) control for common time trends in noise and health.

We exclude data from 2003. As we have only annual noise data, noise exposure in 2003 is a mix of the old flight regime (January to March), the transition flight regime (April to October), and the new flight regime (November and December), and the survey responses could be related to any or several of the three different flight regimes in that year (depending on the exact interview date and the perception period).

Econometrically, we control for endogenous exposure to noise using two features of our data: individual panel data and exogenous within variation in noise exposure because of the flight regime changes. The panel structure allows us to estimate individual fixed effects (FEs) models that do not impose strict assumptions on the relationship between N_{it} and α_i. If noise sensitivity is related to both residential choice and health and is constant over time for each individual (and thus part of α_i), then including individual fixed effects will entirely eliminate the bias in noise effects that arises from this confounding factor. The reason is that in FE models, the time constant α_i is removed by applying the within transformation (e.g. Hsiao, 2003; Wooldridge, 2010). In our case, we employ FE linear probability models (LPM) for all binary health outcomes and FE linear models for the number of doctor consultations and the days affected by health problems. Our findings are robust to the use of (FE) logit models for the binary outcomes and of (FE) Poisson models for the count variables (see Table A1 in the Web Appendix available online and Table A2 for a formal comparison of the linear and non-linear models using information criteria). We use the linear model as main specification because observations with no within-group variation in the dependent variable are dropped from FE logit and FE Poisson models, which changes the interpretation and the generalizability of the results. In addition, unlike with linear models, cross-sectional logit estimates cannot be directly compared with those from a FE model because including fixed effects in a non-linear model like the logit model would change the estimates even if the fixed effects were independent of the variables of interest (Norton, 2012). As we consider only individuals who did not change residence during the study period, individual FE also control for time-constant spatial sorting that is related to both aircraft noise and health. Sensitivity tests reveal that the results remain virtually the same if we do not condition on non-moving people.[3]

4.2. Descriptive statistics

Although using a FE estimation strategy removes the bias from time-constant confounders, it often also removes almost all the variation in the explanatory variable of interest. The key advantage of our data is that we can rely on two quasi-experiments that generate sufficient variation in noise over time and that this within variation is likely exogenous to the individual. Table I shows descriptive statistics of the variation of noise in our data. The mean noise exposure during the day is 40.6 dB(A) and 35.8 dB(A) during the night hour 10 PM to 11 PM. The overall variance for the time span 1999–2005 is more than 15 times larger than the within-individual variance. This can be explained by the fact that the overall variance captures different people living in different places. However, when applying FE, the within variance is more interesting. The within variance of the entire sample between 1999 and 2005 is 2.6 for daytime noise and reduces to 0.1 and 0.4 for years not affected by the changes in flight regulations (2001–2002 and 2004–2005). A similar pattern can be observed for nighttime noise. The within variance of nighttime noise is 3.5 between 1999 and

[3]We do not observe any significant differences in health and noise exposure between non-movers and movers (see Table A3 in the Web Appendix). Given the background information in the SHP, individuals moved because of other reasons than noise, like shorter commuting times, cheaper rents, a change in the personal situation, or a new working place.

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Table I. Summary of noise measures

		Mean	Variance 1999–2005	Variance 2001–2002	Variance 2004–2005
Daytime noise	Overall	40.6	69.5	89.7	52.2
	Within		2.6	0.1	0.4
Nighttime noise	Overall	35.8	63.6	76.4	47.2
	Within		3.5	0.9	1.1
Number of observations	3818				
Number of individuals	1795				

Source: EMPA, own calculations. *Notes*: Daytime noise is the L_{eq} equivalence metric that measures average aircraft noise exposure for the 16-h interval from 6 AM to 10 PM. Nighttime noise is average aircraft noise exposure for the 1-h interval from 10 to 11 PM. Mean values are in dB(A), variation measured as sample variance. Number of observations/individuals from linked SHP/EMPA data.

2005 and only 0.9 and 1.1 for the unaffected years. Thus, more than 70 per cent of the within variance can be explained by the exogenous changes in flight patterns.

Table II shows descriptive statistics for the outcomes we examine. Our sample includes 1795 individuals who contribute 3818 person-year observations. About 25.3% of individuals experience sleeping problems, 34.2 experience headaches, and 33.9 per cent experience weakness or weariness. About 11.7 per cent report being in bad health. On average, individuals went to the doctor nearly three times in the last year and were affected by health problems on over 5 days per year. These numbers are relatively stable over time with less than ten per cent year-to-year variation.

4.3. Estimated noise effects

Table III summarizes the main results of the paper. We estimate the effects of aircraft noise on health using different models, health outcomes, and noise measures. Columns (1) and (2) show the estimated noise coefficients and cluster adjusted standard errors in parentheses from cross-sectional ordinary least squares (OLS) models. Column (1) refers to a basic model specification that includes the noise measure and year fixed effects as the only right-hand side variables. Column (2) adds the control variables.

Table II. Summary of health outcomes

		Mean	Variance 1999–2005	Variance 2001–2002	Variance 2004–2005
Sleeping problems	Overall	0.253	0.188	0.167	0.202
	Within		0.061	0.028	0.046
Headaches	Overall	0.342	0.225	0.217	0.232
	Within		0.066	0.037	0.049
Weakness/weariness	Overall	0.339	0.224	0.200	0.240
	Within		0.079	0.049	0.053
Bad health status	Overall	0.117	0.104	0.096	0.105
	Within		0.041	0.024	0.026
Number of doctor consultations	Overall	2.78	31.1	27.6	34.3
	Within		8.6	6.7	5.5
Days affected by health problems	Overall	5.31	397.5	296.2	531.7
	Within		146.1	91.1	111.9
Number of observations	3818				
Number of individuals	1795				

Source: SHP, own calculations. *Notes*: Sleeping problems, headaches, and weakness/weariness indicate regularly felt health problems (yes = 1/no = 0). Bad health status indicates self-rated health worse than mid point on 5-point scale. The number of doctor consultations and the days affected by health problems relate to the past 12 months and are non-negative count outcomes.

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Table III. Effects of aircraft noise on health

	Pooled models		Fixed effects models	
	(1)	(2)	(3)	(4)
A. Effect of daytime noise on				
Sleeping problems	0.0004	−0.0001	0.0067*	0.0066*
	(0.0011)	(0.0011)	(0.0037)	(0.0036)
Headaches	0.0016	0.0012	0.0101***	0.0103***
	(0.0012)	(0.0012)	(0.0039)	(0.0039)
Weakness/weariness	−0.0003	−0.0003	0.0025	0.0029
	(0.0011)	(0.0011)	(0.0044)	(0.0044)
Bad health status	−0.0006	−0.0008	−0.0008	−0.0006
	(0.0007)	(0.0008)	(0.0032)	(0.0032)
Number of doctor consultations	0.0084	0.0037	−0.0368	−0.0377
	(0.0146)	(0.0149)	(0.0396)	(0.0390)
Days affected by health problems	−0.0006	−0.0171	0.1040	0.0966
	(0.0397)	(0.0415)	(0.1660)	(0.1660)
B. Effect of nighttime noise on				
Sleeping problems	0.0014	0.0012	0.0062*	0.0059*
	(0.0012)	(0.0012)	(0.0034)	(0.0034)
Headaches	0.0021	0.0017	0.0033	0.0035
	(0.0013)	(0.0013)	(0.0037)	(0.0037)
Weakness/weariness	0.0011	0.0013	0.0038	0.0042
	(0.0012)	(0.0012)	(0.0036)	(0.0036)
Bad health status	−0.0005	−0.0005	0.0002	0.0005
	(0.0008)	(0.0008)	(0.0027)	(0.0027)
Number of doctor consultations	−0.0045	−0.0051	−0.0026	−0.0016
	(0.0141)	(0.0143)	(0.0340)	(0.0331)
Days affected by health problems	−0.0273	−0.0365	0.0671	0.0647
	(0.0401)	(0.0404)	(0.1270)	(0.1280)
Number of observations	3,818	3,818	3,818	3,818
Time fixed effects	yes	yes	yes	yes
Control variables	no	yes	no	yes
Individual fixed effects	no	no	yes	yes

Source: Linked SHP/EMPA data, own calculations. *Notes*: Linear regression coefficients for each of the four binary and two count health outcomes. Columns (1) and (2) are pooled OLS regressions, columns (3) and (4) are FE/Within regressions. Models are estimated separately for daytime and nighttime noise. Standard errors (in parentheses) are robust and clustered at the individual level. Variables are described in Table II. FE controls include log income, job change, number of kids, marital status. Pooled controls additionally include gender, age, education, and Swiss nationality.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.01$.

Columns (3) and (4) display the results from the same type of models but including individual fixed effects. Panel A shows the results for the effects of daytime noise and Panel B for nighttime noise.

The results from the pooled cross-sectional model show no relationship between aircraft noise and health. All coefficients are very small and statistically insignificant.[4] In sharp contrast to the pooled models, the FE models suggest a significant increase in sleeping problems and headaches caused by additional daytime aircraft noise and a significant increase in sleeping problems caused by additional nighttime noise. The results indicate that a 1 dB(A) increase in daytime noise exposure leads to a 0.7 percentage point increase in sleeping problems

[4]One concern with linking noise pollution data to survey data is that perhaps individuals find it difficult to recall health problems related to noise when asked about them in a general survey. However, while measurement error in our outcome variables could generally reduce our statistical power and increase standard errors, it will not bias the estimated impact of noise pollution on health. Furthermore, the fact that we find significant effects in the FE models strongly suggests that measurement error is not driving our lack of results in the pooled models.

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and a 1 percentage point increase in headaches, whereas a similar increase in nighttime noise leads to a 0.6 percentage point increase in sleeping problems.[5]

Although aircraft noise has a detrimental effect on sleeping problems and headaches, we find very small and insignificant effects on the general health outcomes in our FE models. This is perhaps not surprising as the domains where we find effects are those that we expect to be most sensitive to environmental disturbances. The general outcomes reflect overall assessments of health with noise exposure being just one of multiple determinants. The insignificant effect on the number of doctor consultations is also unsurprising, given that individuals have mandatory yearly deductibles.

The fact that the detrimental impact of aircraft noise on sleeping problems and headaches is significantly larger in the FE models than in the pooled models is consistent with individuals self-selecting into noise exposure based on their individual vulnerability and noise sensitivity. As noise-sensitive people are more prone to sleeping problems and headaches (Fyhri and Klaboe, 2009) and tend to live in quieter neighborhoods, cross-sectional models underestimate the true causal effect of aircraft noise on these health outcomes. Assuming that noise sensitivity is a time-constant personality trait, FE models correct for this type of sorting bias and provide an unbiased estimate of the causal effect.

Another explanation for why the health effects are larger in the FE models than in the pooled models is habituation. If some people get used to noise over time and if this adjustment process occurs slowly (Griefahn, 2002), the association between noise *levels* and health in the pooled models will be weaker than the association between unexpected aircraft noise *changes* and health in FE models. A further aspect that has to be taken into account is avoidance behavior (Neidell, 2009). People in noisy regions are more likely to sleep with closed windows, for example. While such avoidance behavior generally leads to a downward bias in the effect of noise on health, it is unlikely to explain the difference in health effects between the FE models and the pooled models because people can promptly change their behaviors when noise exposure changes.

Controlling for a variety of observed characteristics does not alter our results.[6] In the pooled models, these added controls do not help to mitigate the sorting bias that is captured by individual fixed effects.[7] In the FE models, the results are stable regardless whether we control for time-varying variables such as job change, income shocks, or divorces. This is re-assuring for our identification strategy because it supports our argument that we are examining exogenous variation in aircraft noise once individual and time fixed effects are controlled for, and it confirms our causal interpretation of the estimated effects of aircraft noise on health in columns (3) and (4) of Table III.[8]

5. CONCLUSION

This paper provides quasi-experimental evidence of the effect of aircraft noise on health for people around Zurich airport. We find that aircraft noise significantly increases sleeping problems and headaches in FE models

[5]Very similar results are found when estimating pooled discrete choice models for the binary health outcomes (see Table A1 in the Web Appendix). When we estimate models in which the daytime and nighttime noise measures are jointly included, the results are nearly identical but estimated with slightly less precision because of the multicollinearity between the two noise measures (see Table A4 in the Web Appendix). The results of random effects (REs) models are similar to the results of the pooled OLS models (see Table A5 in the Web Appendix).

[6]Table A6 in the Web Appendix shows the full covariate results in the pooled and FE models for the effect of daytime noise on sleeping problems.

[7]Although a few control variables (e.g. Swiss nationality and marital status) correlate with both health outcomes and noise exposure, the correlations become insignificant conditional on the year fixed effects.

[8]We conducted a series of robustness checks to explore the two experiments in more detail. First, by restricting the sample to waves 2001 and 2002 only, or 2004 and 2005 only, we excluded the exogenous variation from the sample (and almost all within variation). We do not find any effects in these two subsamples (see Tables A7 and A8 in the Web Appendix). Instead of pooling the two experiments, we also looked at the impacts of the two experiments separately. The magnitudes of the effects remain virtually unchanged, but standard errors are slightly higher because of lower sample sizes (Table A9 in the Web Appendix). We therefore decided to pool both experiments to increase statistical power.

that control for time-constant individual heterogeneity and spatial sorting. Pooled models without FE substantially underestimate the negative health effects. One explanation of this difference in estimates is residential sorting because of a person's noise sensitivity. If noise-sensitive and otherwise vulnerable individuals self-select into quiet regions, the population there is negatively selected with respect to pre-existing health inputs. As noise sensitivity is largely genetically determined (Heinonen-Guzejev *et al.*, 2007) and therefore stable over time, individual FE controls for this type of residential sorting.

Although FEs have become a popular tool to identify causal effects from field data (e.g. Neidell, 2009; Coneus and Spiess, 2012; Graff Zivin and Neidell, 2012), we are the first to use panel data and individual FE to study the effect of aircraft noise on health. Individual FE control for time-constant and health-relevant differences between individuals, such as pre-determined health through genetic predisposition. A downside to this approach is that sufficient within-subject variation is required. We show that quasi-experiments can be used as a credible source of this needed within-subject variation.

6. CONFLICT OF INTEREST

The authors have no conflict of interest. No ethics committee or institution had to approve this paper.

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