# Perception vs. Reality:

## The Aviation Noise Complaint Effect on Home Prices

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**Abstract**

Intercity air transportation has grown rapidly in recent decades and creates significant noise pollution that affects health. Previous research quantifies the losses that are capitalized into home values. Much research relies heavily on spatially restrictive noise contour plots to identify the house price discounts and determine economic damages. We break new ground by investigating whether residential noise complaints can offer insights on aircraft noise pollution and housing price impacts experienced by residents near Minneapolis-Saint-Paul International Airport outside of contour boundaries. Our findings indicate noise complaints are a reliable measure of residential noise annoyance and have a significant adverse effect on home prices extending nearly twice as far (10 km) as contours. Reevaluating economic damages based on our results indicates contour-based calculations severely underestimate aircraft-noise-pollution-induced losses incurred by homeowners and suggests $154 million of $167 million in post-abatement damages are borne by residents located outside the regulated Minneapolis contour area.

**JEL codes**: (R2, R3)
**Key words**: Airport Noise, House Prices, Soundproofing, Abatement Policy

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# 1 Introduction

Disamenities, such as aircraft noise pollution, can adversely affect physical and mental health.[1] Proximity to noise can decrease the desirability of living in noisy locations. In turn, this can impact house sales prices. One can rely on the more general work by Rosen (1974), which postulates house values are comprised of the value of their characteristics, to value the noise disamenity. Banzhaf and Farooque (2013) provide a recent overview of how environmental amenities and disamenities, more generally, are incorporated into the hedonic house price framework.

An established body of research has made important advances in quantifying how aircraft noise is capitalized into home sale prices (see, for example, the meta-analysis by Nelson (2004) and a study by Schomer (2005); or more recent research by Boes and Nüesch (2011) or Affuso et al. (2019)). A broader literature focuses on other types of noise impacts, including rail noise (Chang and Kim 2013), and road traffic noise (such as Kim et al. (2007) and Brandt and Maennig (2011)). While other research suggests airport noise is a common "complaint" (such as Lawton and Fujiwara (2016)), much of the literature relies heavily on noise contour plots to identify the relevant local levels of noise pollution. But some researchers have criticized the use of noise contours to measure noise pollution. Sobotta et al. (2007), for example, indicate how several reports by U.S. federal government agencies (such as the Government Accountability Office and the Environmental Protection Agency) highlight that airport noise contours underestimate the level of noise exposure by residents. This underscores the potential importance of considering other metrics, such as complaints. Gillen and Levesque (1994) find that the probability of additional complaints is increasing with the level of noise near airports, as well as with several other economic and socio-economic variables.[2,3]

In Europe, Fujiwara et al. (2017) consider the many details related to airport noise contour plots, which in and of themselves are a separate scientific field of study. In the United States, these federally regulated contour plots, however, are based on mathematical models that depend on estimates of the average decibels of day-night average sound levels (abbreviated as DNL), and do not necessarily measure the actual noise annoyance levels experienced by local residents at one particular time during the day or season of the year (Schomer 2005). Moreover, the noise contour plots tend to be geographically restricted, only including areas that experience aircraft noise pollution in excess of the relevant thresholds deemed significant by the respective regulators (often starting at 55 dB DNL or higher). As a result, contour plots may be imprecise estimates of individual residential noise experience and underestimate the adverse effects of aircraft noise pollution in some locations as well as at times of day when flight traffic is particularly high.

As one might suspect, the contour thresholds of significant and harmful aircraft noise pollution, in fact, vary across countries. In the United States, 65 dB DNL is deemed to be disruptive of sleeping, thinking, and conversations (Federal Aviation Administration 2000) and has therefore been set as the significant threshold of aircraft noise pollution by the Federal Aviation Administration (FAA) (Federal Aviation Administration 2018).[4] Many U.S. airport authorities, however, publish contour curves that indicate noise pollution below this threshold at the 60 or even 55 dB DNL. In contrast, the European Union Aviation Safety Agency (EASA) has defined two significant noise thresholds: one at the 55dB sound pressure levels averaged over the year for the day, evening and night time periods (Lden), and the other at the 50dB sound pressure level averaged over the year during night time periods only (Lnight) (European Commission 2002).[5] At such peak times of intercity air transportation, when sleeping and normal conversations are disrupted, residents may be inclined to file complaints.

More recently, new guidance deems aircraft noise annoyance significant above Lden $>$ 45dB and Lnight $>$ 40dB (World Health Organization Europe 2018).[6] These revisions are indicative of the fact that existing noise contours may not capture the true annoyance - both in the areas covered by contours and beyond. Since noise regulation and abatement typically uses contour plots (Metropolitan Airports Commission 2019b), the implications of these disconnects may be significant.

The current paper exploits data on nearly 1,000,000 resident noise complaints as an alternative measure of aircraft noise pollution and estimates the complaint effect on Minneapolis home values from 2006 through 2017. The key advantage of the complaint-based approach to evaluating the noise discount on home sale prices is the spatial coverage that reaches far beyond the contour thresholds. This broader coverage allows us to test whether noise pollution affects residents beyond abatement-eligible areas near the airport and improves the estimate of total aircraft noise pollution damages. The primary findings suggest noise complaints are indeed positively correlated with aircraft noise pollution and a 10% increase in annual local noise complaints reduces property values by around 0.05%, on average. This noise pollution effect, persists for roughly 10 kilometers (km) past the airport  nearly twice the distance of the outer most contour curve.

Further, the estimates show noise complaints have nearly identical prediction accuracy of sale prices among home sales within the contour sample and are representative of noise pollution beyond these thresholds. Against the counterfactual of zero residential noise complaints, aggregate economic damages attributable to aircraft noise pollution from the Minneapolis-Saint Paul (MSP) International Airport amount to \$167 million (in 2017 \$) in lost home value on Minneapolis home sales during our 2006 through 2017 sample. Less than 10% of these losses occur for abatement eligible homeowners experiencing noise pollution above the 'significant' noise thresholds, whereas abatement ineligible residents selling homes outside of the traditional contour plots shoulder more than 90% of the noise pollution damages.

One reason this is important is that past studies, such as Wolfe et al. (2016), have found abatement is more cost effective than trying to reduce aircraft noise emissions. Without identifying all homeowners who experience significant noise, it could be challenging to adequately address this noise externality. Indeed, more than half of the recorded noise complaints fall outside the contour areas. Using noise complaints, either as an alternative to or as a supplement to noise contours, could provide policy makers with a more complete picture and enable them to implement abatement policies more closely targeted to those who are affected by the noise.[7]

Overall, the \$154 million of out-of-contour losses and \$13 million of within-contour damages account for around 1% to 2% of the overall sale value. This finding is in line with the contour-based estimate that a one dB DNL increase in contour-measured noise pollution lowers home values by 0.5% and agrees with much of the previous literature discussed in following section (see, for example, (Boes and Nüesch 2011)).

The present study contributes to the literature in several ways. First, using complaints data is unique. In addition to our contour-based analysis, this complaint-based analysis provides further evidence of the adverse effects of aviation noise. This complaints data extends beyond the lower noise contour thresholds of 50 dB DNL or 55 dB DNL. A comparison of the contour- and complaint-based estimates leads to new insights on the distribution of noise pollution effects between contour and non-contour areas. Finally, there is policy relevance that can help airport planners and regulators managing air transport and deciding whether, how, and by how much to compensate affected homeowners.

The remainder of this paper continues as follows. Section 2 provides a discussion of the empirical approach, while section 3 summarizes the data. The empirical findings are presented in section 4. Finally, section 5 offers concluding remarks summarizing the key findings and discussing the potential policy implications.

# 2 Approach

Our approach is twofold. First, we examine whether the observed contour-based noise levels are correlated with complaints. And second, we evaluate how noise complaints impact house prices.

## 2.1 Noise Contour and Complaint Correlation

The MAC launched its noise complaint program in 2006 and has since established a 24-hour noise complaint and information hotline. Their goal is to use these complaints data to ”log, monitor and analyze concerns of airport neighbors, identify trends, and communicate with customers about their concerns.” (Metropolitan Airports Commission 2018). The MAC has reported that complaint data are also used by some city governments (Metropolitan Airports Commission 2019a). To register a complaint with the MAC, a resident can call or file an electronic complaint report (see Figure 4 in the appendix) and must provide a location and other details, such as date, time, and description of the activity of concern (Metropolitan Airports Commission 2018). A person may file several noise complaints, each of which will be logged separately.[8] Failure to provide specifics related to the noise event will terminate the complaint.

To establish whether these noise complaints are a reasonable measure of aircraft noise pollution and a feasible alternative to noise contour plots, a first step investigates whether the mathematically modeled and traditionally used noise contours have any predictive power over noise complaints. The baseline approach to establish this contour-complaint correlation employs the Ordinary Least Squares (OLS) estimator. Specifically, this analysis models annual ($y$), grid-level ($g$) noise complaints ($C_{gy}$) as function of annual grid-level contour noise pollution ($N_{gy}$) and other characteristics, including total population ($Pop_{gy}$) and the percentage of the population that is Caucasian ($W_{gy}$).[9] Moreover, this analysis controls for overarching trends, such as the rising popularity of the noise complaint program, or spatial characteristics via year ($\alpha_y$) and county ($\alpha_s$) fixed effects. Consequently, the baseline OLS model can be expressed as follows:

$$C_{gy} = \beta_0 + \beta_1 N_{gy} + \beta_2 POP_{gy} + \beta_3 W_{gy} + \alpha_y + \alpha_s + \epsilon_{gy}. \tag{1}$$

Departing from this baseline specification, we acknowledge that noise complaints are perhaps more appropriately modeled as a count variable and that many of the annual grid-level complaint observations are zero valued. Because of these features of the data, we test the robustness of the initial OLS results against the application of alternative estimators that may be better suited to model the complaint data. A model comparison between the original OLS specification and multiple count models, including the Poisson (PRM), Negative Binomial (NBRM), and Zero-Inflated Negative Binomial (ZINB) estimators, reveals that ZINB is, in fact, the most appropriate technique. Both the Akaike (AIC) and Bayesian Information Criteria (BIC) reported in Table 5 in the appendix strongly suggest the use of ZINB.

The critical distinction of the ZINB estimator lies in the treatment of the disproportionate number of zeros. Under ZINB, the researcher assumes that there are two processes producing these zero-valued observations. In this context, one might argue that one of these processes that creates zero grid complaints arises as result of negligible noise pollution experienced by local residents. These observations, in fact, represent meaningful zeros with regard to the aircraft noise pollution information conveyed in residential noise complaints. The other processes that create zero-valued complaint observations, however, arise in the presence of significant noise pollution when there is an absence of local residents and/or a lack of knowledge about the MAC's complaint program among the adversely affected residents. These possibilities can create zero-inflating data generating processes that are explicitly modeled here via the ZINB estimator. The log-likelihood function of average grid complaints is modeled as dependent on the aforementioned noise and demographic grid-level characteristics, as well as year and county fixed effects as given in Equation (1). In contrast, the zero-inflating process is modeled as a function of the number of potential complainers, measured by grid-level population, and year fixed effects to account for the increasing popularity of the complaint program.[10]

## 2.2 The Hedonic Model and Noise Complaints

After investigating and uncovering the expected positive correlation between noise complaints and noise pollution measured via MSP contour curves, the next step in this analysis is an estimation of the adverse noise pollution externalities capitalized in house values. To this end, we build on the hedonic literature and model the log of home $i$'s sale price at time $t$ ($ln(P_{it})$) as a function of annual neighborhood characteristics ($BGC_{bt}$), including block-group ($b$) population and the percentage of white block-group residents. Additional controls include time-invariant housing characteristics ($H_i$), such as the year a home was built, the number of bedrooms, bathrooms, and fireplaces, as well as the parcel's square footage. Macroeconomic housing market trends and seasonality of house sale prices are captured via year ($\alpha_y$) and month ($\alpha_m$) fixed effects, respectively.

Conditional on these control variables, the primary relationship of interest determines the home value discount with respect to aircraft noise pollution. In line with the previous literature, home-specific noise pollution in annual dB DNL ($N_{it}$) is measured by mapping a parcel's location relative to the model-based MSP contour plots. Given that some homes are sold at the beginning of the year prior to realizing the full year's average noise pollution, one might be concerned about look-ahead bias. To address this concern, we lag home-specific noise pollution by one year ($N_{i,t-1}$).[11] Akin to the previous analyses by Friedt and Cohen (2021), here these adverse noise effects are differentiated across homes that are abatement eligible ($\delta_{iy}$) and those that are not. The resulting estimation equation is given by

$$ln(P_{it}) = \beta_0 + \beta_1 N_{i,t-1} + \beta_2 N_{i,t-1} * \delta_{iy} + \beta_3 BGC_{it} + \beta_4 H_i + \alpha_y + \alpha_m + \epsilon_{it} \quad (2)$$

and is restricted to a sample of home sales located within MSP contours.

Extending the work of the previous literature, the analysis departs from the restrictive noise contours and utilizes residential noise complaints ($C_{it}$) as an indicator of aircraft noise pollution. Given the wide dispersion of the complaints data, the natural logarithm of noise complaints is used, and only house sales in the vicinity of complaining residents are considered.[12] Similar to the previous specification, the look-ahead bias is avoided by lagging annual noise complaints by one year ($C_{i,t-1}$). Further, we delineate the complaint effect across homes that are abatement eligible and those that are not. Unlike the contour-based noise pollution approximations, noise complaints are not limited to the geographic area directly surrounding the airport and instead span across a multitude of communities. To capture the inherent differences in house sale prices across these neighborhoods, community fixed effects ($\alpha_{com}$) are included in the complaint specification. The primary estimation equation is given by

$$ln(P_{it}) = \beta_0 + \beta_1 C_{i,t-1} + \beta_2 C_{i,t-1} * \delta_{iy} + \beta_3 BGC_{it} + \beta_4 H_i + \alpha_y + \alpha_m + \alpha_{com} + \epsilon_{it}, \quad (3)$$

where $\epsilon_{it}$ represents the random error term. Note that the hedonic approach is a demand-side approach. Therefore it assumes buyers are aware of the noise levels (opposed to any information asymmetry between the buyers and sellers). Therefore, we assume perfect information on the part of home buyers.

# 3 Data

In order to evaluate the capacity of residential noise complaints to provide a reasonable and correlated measure of aircraft noise pollution and quantify the resulting home price discounts, multiple datasets are combined into two novel datasets aggregating information at the grid and property levels. The data include information on noise complaints, contour curves, home sales, as well as parcel and block group characteristics from a variety of sources.

The key variables of interest are given by Minneapolis homes sale prices, residential noise complaints, and contour curves for MSP. Information on noise contours and complaints are published annually by the MAC and span a time period from 2006 to 2017. Noise contours, which measure the annual average Day-Night Sound Levels produced by intercity air transportation facilitated by MSP (a Delta Airline hub), are available at an annual frequency and distinguish noise pollution from the lower 60 dB DNL threshold to an upper limit of 80 dB DNL, typically disaggregated into one dB DNL increments.[13] Figure 1.1 illustrates the outermost 60 dB DNL contour curve approximating MSP aircraft noise pollution relative to the seven Minnesota counties surrounding the airport in 2016. Among the sample of Minneapolis home sales located within these contours, aircraft noise pollution, measured via contours, averages 61.9 dB DNL with a standard deviation of 2.14 dB DNL (Panel B, Table 1). Given the geographic limitations of these contour curves as depicted in Figure 1.1, one can associate this type of noise measurement with only 3,074 home sales out of 37,477 total transactions. On average, these properties are located about 2.8 km from the airport.

## 3.1 Grid-Level Data

In contrast, the MAC records residential noise complaints at an hourly frequency and maps this potential indicator of aircraft noise annoyance into 7,402 sample grids (0.5 miles by 0.5 miles) spanning over the seven counties of the greater Twin Cities metropolitan area (see Figures 1.1). In total, the MAC has recorded nearly 1,000,000 residential noise complaints during the 2006 to 2017 sample period, around 310,000 of which occurred in Minneapolis alone. In order to create a complaint noise measure comparable to contour DNLs, we aggregate these real-time grid-level noise complaints to an annual frequency. Annual complaint counts are a more appropriate measure of aggregate residential noise annoyance than contemporaneous complaints during the day or even month of a property's sale. Figures 1.1 and 1.2 depict the spatial distributions of these grid-level complaints (relative to noise contours) over the seven Minnesota counties surrounding MSP and the Minneapolis communities for 2016.

[INSERT FIGURES 1.1 AND 1.2]

The graphs communicate two primary facts. First, noise complaints are more heavily concentrated in close proximity to the airport. Noise complaints rise with aircraft noise, which increases near the airport as aircrafts operate in lower altitudes to approach or depart from MSP. This is an important observation because, unlike contour-based noise measures, noise complaints require individual residents to report noise annoyance. One might argue residents locating near the airport are less noise-adverse than others and will therefore complain less; even though actual noise pollution is high near the airport. Consequently, one potential concern is that the complaint-based approach underestimates noise near the airport and therefore attenuates the noise-complaint correlation and complaint-based noise discount estimates. Given the apparent rise in complaints near the airport shown in Figures 1.1 and 1.2, this appears to be less of a concern.

Second, the figures clearly indicate that a significant degree of residential noise annoyance is reported beyond the lower 60 dB DNL threshold represented by the outer most contour. Based on the sample, nearly 750,000 of the recorded complaints are attributed to grids that do not overlap with noise contours. This accounts for more than 75% of the total number of complaints. Accordingly, if noise complaints offer a reasonable indication of aircraft noise pollution, the human experience and discontent with this disamenity seems to reach beyond the 'significant' noise thresholds set by regulators and the adverse implications of noise pollution appear to reach much farther than indicated by traditional contour curves.

Panel A of Table 1 provides further details on annual grid-level complaints as well as summary statistics on grid-specific characteristics, such as contour-based noise pollution, the number of home sales, and total population per grid. Both, the contour-based noise pollution and demographic characteristics are spatially weighted averages, where the weights represent the share of the grid overlapping with a specific contour curve or specific 2010 Census block group. The statistics reveal that the average grid records 10.5 complaints per year, but that the distribution of complaints is over dispersed with a standard deviation of 214.64. Most of the 88,824 grid-year observations, in fact, indicate no aircraft noise complaints. Among the grids for which the MAC reports annual grid complaints, the average number of incidents reaches 190, with a median of eight and a standard deviation of 897. In Minneapolis, grid complaints average 307 per year with a standard deviation of close to 950 annual complaints.

[INSERT TABLE 1 HERE]

In line with the fact that noise complaints are rare and heavily concentrated among grids in close proximity to the airport, panel A of Table 1 further reveals that most grids do not intersect with any contour curves and that annual contour noise averages merely 0.38 dB DNL per grid. A calculation of the complaint-to-contour-noise ratio supports the initial hypothesis that noise complaints are positively correlated with the traditional measure of aircraft noise pollution. Among the 895 annual grid observations that overlap with noise contours we observe around 400 residential noise complaints per dB DNL, on average. Among Minneapolis grids, the mean of this ratio rises to nearly 1,200 complaints per dB DNL. Interestingly, even among these contour-overlapping grids, we observe some areas without any noise complaints, which might be the result of the absence of residents and/or the successful implementation of the aircraft noise abatement program alleviating the residents' noise annoyance.

One interesting question to consider is what drives these residents to complain. Is it annoyance with prolonged exposure to high levels of noise or do residents complain in response to deviations from the 'norm'? In the absence of detailed information on flight traffic, this question is difficult to answer. Nonetheless, an aggregation of daily complaints across the northeast, northwest, southeast, and southwest quadrants relative to the airport can shed some light on this issue. Daily flight patterns are impacted by changing winds, which can lead to unusually high traffic in one direction and lower traffic in other directions on any particular day. As a result, one might expect daily noise complaints to be negatively correlated over space if these are driven by deviations in noise from the 'norm'. The evidence is mixed. While complaints in the NW quadrant are positively correlated with complaints in other three areas, there is some evidence of switching complaint patterns south of the airport.

Relatedly, an important question concerns the tenure of complaining residents. Are complainers long-term residents who understand deviations from the 'norm' or are they newcomers who (perhaps unknowingly) recently relocated to a noisy area. In the latter case, changes in complaints are unlikely to reflect changes in noise pollution, and instead are simply correlated with residential mobility. This would weaken our complaint-based approach. While the complaint data are anonymous and do not shed any direct light on this particular issue, we are able to match grid complaints with Census-based information on geographical mobility. Reassuringly, simple correlations show that noise complaints tend to fall with the population share of movers (see Figures 5.1 and 5.2 in the Appendix) suggesting that more complaints arise in grids with a greater population share of long-term residents.

Additional statistics that characterize our sample of annual grids include the number of Minneapolis house sales, the size of the grid population, and the percentage of grid population that identifies as white. On average, we observe 23.5 home sales per Minneapolis grid per year. Based on the 2010 U.S. Census and 2013 through 2017 American Community Surveys, we approximate annual grid-level population at 387 with a standard deviation of 645. Among this grid population, roughly 90% consider themselves Caucasian on average.

## 3.2 Property-Level Data

Similar to mapping house sales to aircraft noise pollution based on contour curves, mapping these sales against annual grid-level complaint counts creates a few challenges. Since residential noise complaints are recorded at a grid level to preserve anonymity, each home sale can be associated with a specific grid, but complaints cannot be matched to the individual properties. These varying levels of aggregation are of no consequence if residential noise complaints are uniformly distributed within each grid, but can be problematic if complaints are geographically concentrated within grids.[14] This issue is not unique to grid-level noise complaints, but also arises in the contour case, where geographically continuous aircraft noise pollution is approximated via discontinuous

DNL thresholds. The problem is most pronounced at the outer most contour curve, where residents just inside of the barrier are approximated to experience noise pollution at 60 dB DNL, whereas homeowners just outside this contour appear to experience zero noise pollution according to the contour map. True aircraft noise pollution is continuous across these thresholds. Remedies for this exacerbated discontinuity in the contour case are not obvious and the persistence of this issue has led to the reevaluation of significant noise thresholds in Europe (World Health Organization Europe 2018).

Noise complaint grids are spatially more disaggregated than contour plots and span a wider area. As a result, it may be possible to mitigate this issue and create a more holistic measure of local aircraft noise pollution by determining the 'local' level of noise complaints for each unique property. To this end, the nearest four grids to each parcel are identified and the house-specific inverse-distance-weighted aggregate noise complaints across these four grids is calculated. This measure of 'local' noise complaints is a better representation of local aircraft noise annoyance and smooths out the spatial discontinuities given by grid boundaries. In other words, a larger set of information on noise complaints recorded within each property's vicinity (not just its grid) is taken into account and the resulting noise measure is likely much less susceptible to the previously indicated issue. Consider, for example, the case of noise pollution mismeasurement, where a significantly noise-polluted home is situated near the edge of a grid and appears to face low exposure to aircraft noise due minimal grid-level noise complaints. Since the surrounding grids closest to this particular property are likely to reflect a similar level of noise annoyance as experienced by the edge-case property, the proposed local complaint measure would reduce the mismeasurement aggregating across all four grid complaint counts.[15]

As illustrated in Panel B of Table 1, aggregation over the nearest four grids takes account of the local geography of noise complaints smoothing out local outliers and accentuating broader trends of low to high levels of noise annoyance. The average Minneapolis home in our sample is located in a grid recording around 307 annual complaints, whereas the distance-weighted measure indicates an average of 323 local noise complaints. The maximum value of 97,962 noise complaints for the weighted aggregate, however, indicates that the severity local aircraft noise pollution may be much greater for certain areas than indicated by the grid-specific complaint count with a maximum value of 20,666.

The outcome variable of interest is given by Minneapolis home sale prices from 2006 through 2017. These data were generously provided by Professor Sarah West and Clemens Pilgram, who study the housing price premiums of the Minneapolis Blue Line light rail (Pilgram and West 2018) and were originally obtained from the City of Minneapolis' Tax Assessment Office. The records include all arm's length transactions of single-family home sales in Minneapolis between 2000 and 2017. Given the availability of noise complaint data, however, we restrict the sample to market transactions from 2006 to 2017.[16] The remaining sample includes 30,375 properties for which a unique identification number is observed along with the corresponding home address, the date(s) of sale, and the nominal sale price(s). We adjust the nominal sale prices for inflation via the Consumer Price Index for all Urban Consumers, sourced from the Bureau of Labor Statistics (BLS), and express real property values in 2017 U.S. dollars.

Panel B of Table 1 illustrates that the average Minneapolis home in the sample commands an average sale price of around $282,000 with a standard deviation of $208,000. Most of these Minneapolis homes report a single sale during the 2006 to 2017 sample period, while the most frequently sold property reports a total of six transactions during this time frame. Among the repeatedly sold homes, Panel C of Table 1 shows that the duration between sales averages around 60 month and that the number of local noise complaints between these transactions tends to increase by around 280 records, on average.

Based on the unique parcel identification numbers, the latest information on parcel characteristics is matched using the 2019 Assessor's Parcel Data publicly available through the Open Minneapolis database published by the City of Minneapolis. The relevant control variables include, for example, the number of bedrooms, bathrooms, and fireplaces, as well as the each parcel's square footage and the year it was built. Panel B of Table 1 shows that the average Minneapolis sample home was built in 1940, offers two to three bedrooms and around two bathrooms, and sits on average on a parcel of 18,056 square feet located about 6 km away from the MSP international airport.

Additional control variables include neighborhood characteristics that are drawn from the 2010 U.S. Census and complemented by the estimates provided by the American Community Survey 2013 through 2017. The information is disaggregated at the block group level and includes the total block group population as well as the percentage of the population that identifies as Caucasian. To attribute these neighborhood characteristics to the individual home sales, each parcel is mapped into the 2010 Census block groups using the MetroGIS parcel data published by the Twin Cities Metropolitan Council in April of 2014. Missing neighborhood characteristics for the years 2006 through 2009 and 2011 through 2012 are linearly interpolated. Panel B of Table 1 reveals that the average Minneapolis home is located in a block group of around 1,082 residents, approximately 76% of whom consider themselves Caucasian, on average.

# 4 Results

In this section, we present the primary findings. First is a discussion of the complaint-contour correlation and then focus is turned towards investigation of the noise complaint effect on residential property values. While the initial analysis is based on the entire annual grid-level sample across all seven Minnesota counties of the greater Twin Cities' metropolitan area, the subsequent hedonic analysis is centered on Minneapolis, for which property transactions are observed. Across all specifications, heteroscedasticity robust standard errors are reported.

## 4.1 Noise Contour and Complaint Correlation

To answer the initial question of whether residential noise complaints are a reasonable measure of noise annoyance resulting from aircraft noise pollution, we begin by graphing the raw correlations between noise complaints and contour noise at the grid (Figure 2.1) and the Minneapolis property levels (Figure 2.2). As suggested by the summary statistics presented in Panel A of Table 1, most of the 7,402 grids do not overlap with noise contours. Yet, many of these grids record positive noise complaints and are, thus, bunched at the zero lower bound shown in Figure 2.1. For those grids that (at least partially) fall within noise contour curves, however, there is a slight rise in noise complaints as indicated by the upward sloping trend given in Figure 2.1.

[INSERT FIGURES 2.1 and 2.2 HERE]

At the property level, there are similar challenges as most home sales fall outside the given contour curves. To overcome this issue, we calculate a rough prediction of contour noise levels for each transaction based on an OLS regression that interacts a parcel's distance to MSP with annual fixed effects to approximate the geographic and temporal variation in aircraft noise pollution.[17] Figure 2.2 presents a simple scatter plot of Minneapolis noise complaints against this predicted level of property-specific contour noise. As expected, the predicted contour-based data are noisy, but show clear evidence in support of a positive correlation between the extrapolated measure of aircraft noise pollution based on contour curves and residential noise annoyance captured via noise complaints.

The estimation of the initial model (Equation (1)) provides further evidence of this positive complaint-contour-noise correlation. Recognizing the count characteristic and over dispersion of the MAC complaint data, the fit of alternative count models and a simple OLS model are compared. Based on the AIC and BIC test statistics reported in Table 5 of the Appendix, the zero-inflated negative binomial estimator (ZINB) produces the best fit for the data. The preferred full model ZINB estimates are presented in column (1) of Table 2. Controlling for year and county fixed effects, grid-specific population and ethnicity, and differentiating the correlation between noise complaints and noise pollution across soundproofing eligible and ineligible grids, the estimates suggest that a one dB DNL increase in contour noise is associated with a 6.6% increase in the expected number of annual grid complaints. The coefficient estimate is statistically significant at the 1% level. Similarly, increases in total population and the number of residents that identify as Caucasian also raise the expected number of complaints. Abatement eligibility does not alter the noise-complaint correlation.[18]

[INSERT TABLE 2 HERE]

The zero-inflation equation estimates are presented in Panel B of Table 2 and suggest that increases in grid population, indeed, reduce the probability of observing zero complaints. The more residents that live in a grid, the more unlikely it becomes to observe zero noise complaints. Similarly, the unreported coefficient estimates on the year fixed effects also suggest that the probability of zero annual grid complaints tends to fall over time. As the noise complaint program becomes more popular among local residents over time, it becomes less likely to observe zero grid complaints. Lastly, the statistically significant parameter estimate for $\alpha$ supports the hypothesis that the noise complaint data are, indeed, over dispersed.

Expanding upon these preferred ZINB findings in column (1), we estimate the noise contour-complaint correlation with daytime (column (2) of Table 2) and nighttime complaints (column (3) of Table 2), respectively. Both estimations produce qualitatively and quantitatively similar results suggesting that both daytime and nighttime annual grid complaints rise with greater contour noise. In column (4), the sample is restricted to observations post-2014, after the conclusion of the abatement initiative. The coefficient estimate of interest falls to 0.02, but remains statistically significant at the 1% level. Lastly, the sample is limited to Minneapolis grids and with that restriction a one dB DNL increase in contour noise coincides with a 3.9% increase in the expected number of annual grid complaints. Interestingly, this correlation, however, only holds for Minneapolis grids that are abatement ineligible. In contrast, the complaint-contour correlation is significantly smaller for Minneapolis grids that contain abatement eligible properties (column (5) of Table 2).

In an older study, Maziul et al. (2005) find complaints are not necessarily a reliable proxy for annoyance, and they suggest that other factors should be taken into consideration. But in the context of our research, we demonstrate that observed levels are highly correlated with complaints, implying complaints are a reasonable proxy for annoyance.

## 4.2 Hedonic Complaint Effect Estimates

Overall, the results up until this point provide consistent evidence that residential noise complaints, and the reflected noise annoyance, are positively correlated with the traditional and extrapolated contour measure of aircraft noise pollution. Building on this finding, we estimate the hedonic model evaluating the noise complaint effect on Minneapolis home sale prices and contrast the results against the traditional contour-based measure.

For the sake of brevity, we present the contour-based noise effect estimates and discussion thereof in the Appendix (see, for example, Table 6). Briefly, we find that aircraft noise pollution measured via noise contours causes a statistically and economically significant reduction in sale prices among Minneapolis homes located within these contour curves, while abatement eligibility offsets this effect. The estimated noise discount of 0.5% per one dB DNL is generally consistent with the range of noise contour estimates from other hedonic airport noise studies, but they face a major issue with respect to out-of-sample, out-of-contour-plot predictions. Since one cannot observe the contour-based estimate of aircraft noise pollution beyond the contour curves, the coefficients presented in Table 6 in the Appendix are based on a sample that is restricted to 3,644 Minneapolis homes sales located within the 2006 through 2017 MSP contour curves.

A simple calculation comparing the observed sale price to the predicted counterfactual prices under the hypothetical absence of noise pollution suggests sustained economic aircraft noise damages of around \$22 million. According to the MAC, abatement costs for the 2007 Consent Decree Program totaled \$95 million pushing the realized total contour sample losses due to aircraft noise to around \$117 million. Given that aircraft noise pollution, however, is continuous and is not muted beyond the 60 dB DNL contour boundary, it is plausible that this represents a biased estimate of total economic losses ignoring the economic damages incurred by homeowners residing beyond the contour threshold.

To overcome this issue, the Minneapolis complaint data is considered in order to provide an alternative approach for measuring the adverse effects of aircraft noise pollution in out-of-contour areas. Table 3 presents the estimation results for the effect of noise complaints on home values located outside and inside the MSP noise contour plots. The estimates are based on variations of Equation (3). To begin, we exclusively focus on the noise pollution effects outside of the contour region (column (1)). This sample restriction excludes all abatement eligible properties and therefore excludes the abatement-eligibility interaction term. The parameter estimates in column (1) tend to carry the expected signs and are statistically significant at the 1% level. Homes located in more populated neighborhoods and with higher Caucasian population shares sell for higher prices. Amenities, such as the number of bedrooms, bathrooms, and fireplaces, significantly increase home values. The estimated effects of a parcel's square footage and the year the home was built are negative and significant.[19]

The coefficient estimate of interest shows that a 100% increase in local noise complaints lowers property values for non-contour Minneapolis homes by 0.5% (Table 3, column (1)). Another way to interpret this Minneapolis result is based on the descriptive statistics shown in Table 1 for Minneapolis homes. The mean complaints is 146 and the standard deviation is 692 (roughly 4.5 times the mean). On average, a 100% increase in complaints is approximately 0.21 standard deviations. Therefore, a 0.21 standard deviation increase in complaints leads to a 0.5% decrease in Minneapolis home prices.

As a comparison with our results, Fan et al. (2019) examine the impact of noise complaints from bus transit routes in Singapore, using a two-step approach. First, they estimate how transit impacts noise complaints. In their second step, they estimate how the fitted value of noise complaints impacts house prices. They find that for every 1 scale unit increase in complaint sentiments, house prices fall by approximately 3%. With the mean of the complaint sentiment index of 0.41 and a standard deviation of 0.165, this implies that a 1 scale unit increase in complaint sentiments (roughly 250% increase, on average), which corresponds to a 3 percent decrease in property values, is equivalent to 0.4125 standard deviations in the sentiment, on average. Recall that in our analysis for Minneapolis, a 0.21 standard deviation increase in complaints leads to a 0.5% decrease in house values. Fan et al. (2019) finding is quite large compared with our results (specifically, it is roughly 3 times as large). This may be attributable to the fact that Fan et al. (2019) focus on multi-family residential buildings with differential noise effects across units on different floors, while we focus on single family residential properties in Minneapolis. Also aircraft noise tends to be overhead while bus noise tends to be parallel to the properties (or below, for multi-family apartment buildings). Despite these differences, it is interesting that the Minneapolis complaint effect is smaller than the Singapore complaint effect.

[INSERT TABLE 3 HERE]

To provide further evidence in support of this finding, we expand the sample to include not only out-of-contour home sales, but also within contour transactions. Once again, the inclusion of these observations allows the differentiation between the noise pollution effect across abatement eligible and ineligible properties (as in Equation (3)). The full sample complaint results presented in column (2) of Table 3 are consistent with the out-of-contour sample (see column (1)) and match those obtained with the restrictive contour noise measure shown Table 6 in the Appendix. A 100% increase in local noise complaints reduces sale prices by 0.5% for abatement ineligible homes, whereas homeowners of eligible properties experience a full offset in response to aircraft noise pollution increases.

One important question to consider is how far this noise discount (based on complaint data) reaches beyond the traditional contour curves. To address this question, we expand Equation (3) and integrate an interaction term between local noise complaints and a property's distance to MSP. As expected, the estimates shown in column (3) of Table 3 indicate that properties in closer proximity to MSP experience greater noise complaint discounts than houses located at greater distances. To visualize the spatial decay of the complaint discount, the marginal effects of noise complaints on home values over distance to MSP are shown in Figure 3. The figure shows the noise complaint discount falls with distance and is approximately zero around 10 km from the airport nearly twice the distance from the airport relative to the outer most contour of 60 dB DNL.

[INSERT FIGURE 3 HERE]

In order to compare the estimates from noise contours and noise complaints, the Mean Absolute Percentage Error (MAPE) is calculated for both sets of estimates. The MAPE is a measure of forecasting accuracy when comparing different estimation processes. We use the MAPE to determine how well the hedonic model using each noise metric predicts the actual sales price. To draw this comparison, the sample is restricted to within-contour observations for which the information on both complaints and noise contours are available. Using the noise contour estimates, the MAPE equals 1.45% (Table 6, column 5). On the other hand, the complaint estimates' MAPE equals 1.56% (Table 3, column 6). While the MAPE for noise complaints is slightly higher than the MAPE for noise contours, the two differ by approximately 6%. Given that the noise complaints data cover a much broader range of properties than can be included in the noise contours, the 6% difference in MAPE is not large enough to select the noise contour approach over the complaints approach.

Finally, the noise complaint results reported in column (3) of Table 3 can be used to determine the total losses incurred inside and outside of the MSP contours. Repeating the counterfactual calculations based on the complaint estimates, the total economic damages amount to $167 million, only $13 million of which fall within the contour curves. This within-contour estimate based on noise complaints is quite comparable to the $22 million based on contour noise. In contrast, $154 million, over 90% of total post abatement damages, are borne by homeowners residing outside of the MSP contours, who are ineligible for any abatement subsidies and do not experience harmful noise pollution according to the FAA. This out-of-contour loss estimate is consistent with the assertion by Gillen and Levesque (1994) that noise discounts based on noise contour data underestimate the true value of damages. Further accounting for the $95 million in abatement costs already invested by the MAC over the past decade, the cumulative Minneapolis aircraft noise pollution damages exceed $260 million. Still, this may be a conservative estimate of the true losses due to MSP aircraft noise pollution. The estimation sample consists of Minneapolis property transactions between 2006 and 2017. These home sales are subject to approximately one third of all MSP complaints suggesting that further damages likely arise in the surrounding areas.

## 4.3 Sensitivity Analyses & Limitations

To further test the sensitivity of our findings against potential misspecification of the model and the possible issue of endogeneity due to unobserved housing and/or neighborhood characteristics, we expand the set of control variables. First, we integrate a property's distance to Minneapolis' city center. As column (4) of Table 3 shows, homes at greater distances from the city center sell at significantly lower prices. The coefficient estimates of interest and other control variables are seemingly unaffected by this addition to the model. Second, we expand the set of spatial fixed effects by using grid-specific indicators that capture time-invariant differences across complaint grids. This specification aims to control for unobserved neighborhood characteristics of sold properties at a more disaggregated level. With the exception of the coefficient on the year a home was built, the results shown in column (5) of Table 3 indicate quantitatively and qualitatively consistent parameter estimates.

As part of an another sensitivity analysis, we scrutinize the assumed exogeneity of contemporaneous Census block group population and demographics. One might argue that the number of local residents endogenously responds to local amenities, such as noise pollution, and/or housing market conditions. To address this possible endogeneity concern, we re-estimate the preferred model (Table 3, column (3)) using lagged neighborhood characteristics. Irrespective of the chosen lag length between one and five years, the results remain quantitatively and qualitatively consistent with our primary findings. These estimates are available upon request.

Given the finding that local noise complaints are associated with significant sale price discounts, we broaden the analysis and consider the effects on alternative housing market outcomes. Specifically, the complaint effect on the number of sales per grid per home is considered, along with the duration between sales for repeatedly sold properties. Table 4 details the findings with respect to each to these three outcome variables. At the grid level, we find that conditional on controlling for local population and housing characteristics, a 1% increase in local noise complaints raises the number of grid-specific home sales by 1.27 per year (Table 4, column (2)). This finding suggests that along the extensive margin, greater noise annoyance increases the supply of homes for sale. With respect to the intensive margin, higher levels of noise complaints are also associated with an increase in the number of sales per home. Conditional on neighborhood and property-specific characteristics, a 100% increase in local noise complaints raises the number of sales by 0.3%, while abatement eligibility fully offsets this intensive margin effect (Table 4, column (4)). Lastly, the complaint effect raises the duration between sales among the repeatedly sold homes. For every 1,000 local noise complaints, the duration between sales increases by around 2 months (see column (6) of Table 4). This finding perhaps indicates that greater levels of residential noise annoyance make it more challenging to sell an affected home.

[INSERT TABLE 4 HERE]

Finally, there are some potential limitations to the analysis above. One is that there could be a sample selection issue, as the individuals who choose to complain may have different personalities (i.e., more outgoing and/or aggressive) than people who are still annoyed by the noise but do not complain. Second, grid-level complaints do not allow for heterogeneity within the grid level. It is possible that some individuals in a grid are not annoyed by noise  possibly due to hearing issues or other biological factors  so relying on grid-level complaints may not always map perfectly one-to-one to individual properties. Lastly, the model specification incorporates some of the housing characteristics typically controlled for in hedonic analyses, whereas others, such as the building's quality, are unavailable given the data. Consequently, we cannot control for all fundamentals that may influence house prices. Nevertheless, the results described above move the literature in the right direction towards a more complete understanding of how complaints impact house prices, and therefore this work constitutes an important contribution.

# 5 Conclusion

Intercity air transportation has grown rapidly in recent decades. And although technological progress has made aircraft engines more efficient and less noisy, the resulting aircraft noise pollution and its adverse effects on physical and mental health remains a significant concern for policymakers and residents surrounding large international airports. The vast majority of previous airport noise studies have focused on how contour-based estimates of noise impact house prices. Some research has found this can lead to under-estimates of the noise discount, for a variety of reasons. One reason is the noise estimates may be inaccurate, and in some cases, missing below a certain threshold that the FAA does not classify as harmful (i.e., below 65 dB or in some cases 60 dB or

55 dB).

Focusing on noise complaints as a reasonable indicator of aircraft noise pollution, and how these complaints impact house prices, can be a fruitful alternative. The main advantage of this methodology is that complaints data can provide a more detailed and fuller picture of residential noise annoyance. In the case of MSP, the data offer more detailed insights on noise pollution - both in terms of the timing and geography that reaches far beyond contour boundaries. The main caveat to using data on residential noise complaints is that these must in fact be correlated with actual noise pollution; or else one risks basing inference on spurious correlations. This research on the effect of complaints on house prices is a significant contribution to the literature on intercity air transportation in general, and more specifically, on airport noise studies.

In this paper, the analyses first demonstrate that the probability of additional noise complaints is indeed positively correlated with traditional contour-based measures of noise and therefore a reasonable indicator of aircraft noise pollution. Next this study demonstrates how additional noise complaints impact house prices near the Minneapolis/Saint Paul airport. The results point to economically and statistically significant noise discounts from sales of properties beyond the noise contours. Over 90% of the resulting $167 million in post-abatement economic damages fall outside of the contour area. These out-of-contour damages are not generally picked up in other hedonic noise studies because beyond some lower noise threshold researchers typically assume the noise levels equal to zero.

There could be significant policy implications of these findings. With the noise discount underestimated in many outlying areas, perhaps additional soundproofing would be warranted. Another alternative might be for the federal government to encourage quieter aircraft. According to our finding that noise pollution damages reach far beyond traditional contour areas, the benefits from these technological improvements may be much greater than previously assumed. Altering flight paths to avoid some of these areas with greater complaints is another alternative, especially when there are undeveloped areas that could be candidates for rerouting during times of day when there are heavy complaints. Regardless, this research demonstrates that the damages to society from aircraft noise are likely substantially higher than commonly estimated by airport authorities.

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# Tables and Figures

Table 1: Summary Statistics

| | (1) Mean | (2) Median | (3) SD | (4) Obs |
|---|---|---|---|---|
| **Panel A: Grids** | | | | |
| Annual Complaints | 10.46 | 0.00 | 214.64 | 88,824 |
| Non-zero | 190.69 | 8.00 | 897.42 | 4,874 |
| Minneapolis | 146.31 | 1.00 | 692.61 | 2,112 |
| Annual Noise Pollution (DNL) | 0.38 | 0.00 | 4.57 | 88,824 |
| Complaint to Noise Ratio | 420.11 | 0.00 | 6,364.18 | 895 |
| Minneapolis Ratio | 1,194.70 | 2.00 | 11,079.72 | 293 |
| Annual # of Sales | 23.50 | 19.00 | 20.98 | 2,112 |
| Annual Grid Population | 387.05 | 95.25 | 645.09 | 88,824 |
| Annual Population, White (%) | 90.42 | 94.59 | 10.86 | 88,824 |
| **Panel B: Minneapolis Homes** | | | | |
| Avg. Sale Price ($'000) | 282 | 230 | 208 | 37,477 |
| Avg. # of Sales | 1.54 | 1.00 | 0.70 | 37,477 |
| Dist.-Weighted Annual Local Complaints | 322.77 | 18.01 | 1,111.86 | 37,477 |
| Annual Grid Complaints | 306.58 | 15.00 | 948.03 | 37,477 |
| Annual Noise Pollution (DNL) | 61.89 | 61.00 | 2.14 | 3,137 |
| # of Bedrooms | 2.87 | 3.00 | 1.18 | 37,477 |
| # of Bathrooms | 1.93 | 2.00 | 0.92 | 37,477 |
| Year built | 1940 | 1,928 | 32 | 37,477 |
| Parcel Square footage | 18,056 | 5,754 | 37,949 | 37,477 |
| # of fireplaces | 0.52 | 0.00 | 0.72 | 37,477 |
| Distance to MSP Airport (km) | 5.82 | 5.49 | 2.52 | 37,477 |
| Annual BG Population | 1,081.87 | 999.00 | 425.98 | 37,477 |
| Annual Population, White (%) | 76.05 | 83.28 | 20.05 | 37,477 |
| **Panel C: Minneapolis Repeat Sales** | | | | |
| Duration between Sales (Month) | 59.64 | 57.00 | 32.21 | 9,883 |
| $\Delta$ Local Complaints btw. Repeat Sales | 279.91 | 3.09 | 1,530.58 | 9,883 |

Panel A Notes: The statistics are based on a balanced sample of 7,402 distinct complaint grids generated by Metropolitan Airports Commission (MAC) and aggregated to an annual frequency from 2006 to 2017.

Panel B Notes: The statistics are based on a sample of 37,477 transactions of 30,375 unique Minneapolis homes.

Sources: MAC; 2010 U.S. Census; American Community Surveys 2013 through 2017; City of Minneapolis' Tax Assessment Office

Table 2: Noise Complaints and Pollution Correlations (ZINB)

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| **Panel A: Main Equation** | | | | | |
| Annual Noise Pollution (DNL) | 0.066 | 0.065 | 0.072 | 0.020 | 0.039 |
| | (0.024) | (0.024) | (0.024) | (0.006) | (0.005) |
| Noise $\times \delta_{gt}$ | -0.007 | -0.010 | 0.022 | - | -0.023 |
| | (0.039) | (0.040) | (0.046) | | (0.008) |
| Annual Grid Population ('000) | 1.085 | 1.048 | 1.039 | 0.840 | 0.001 |
| | (0.122) | (0.123) | (0.115) | (0.176) | (0.000) |
| Grid Population, White (%) | 0.048 | 0.048 | 0.068 | 0.072 | 0.081 |
| | (0.006) | (0.007) | (0.005) | (0.009) | (0.005) |
| Constant | -7.616 | -7.594 | -12.370 | -9.741 | -5.020 |
| | (0.654) | (0.669) | (0.565) | (0.948) | (0.620) |
| Year FE | Y | Y | Y | Y | Y |
| County FE | Y | Y | Y | Y | N |
| **Panel B: Inflation Equation** | | | | | |
| Annual Grid Population ('000) | -6.092 | -5.877 | -5.335 | -5.662 | -0.003 |
| | (0.333) | (0.311) | (0.527) | (0.496) | (0.000) |
| Constant | 3.321 | 3.325 | 3.592 | 3.360 | 1.543 |
| | (0.159) | (0.164) | (0.219) | (0.154) | (0.888) |
| Year FE | Y | Y | Y | Y | Y |
| N | 88,824 | 88,824 | 88,824 | 22,206 | 2,124 |
| Zeros | 83,950 | 84,137 | 86,396 | 20,815 | 1,024 |
| $\chi^2$ | 1,438 | 1,359 | 1,420 | 779 | 653 |
| $\alpha$ | 2.920 | 2.936 | 2.831 | 2.827 | 1.870 |

Notes: This table documents the correlation between grid-specific annual noise complaints and noise pollution using the zero-inflated negative binomial estimator (ZINB). Columns (1), (4), and (5) are based on total complaints, whereas results in columns (2) and (3) isolate the noise correlation with day-time and night-time complaints, respectively. In column (4) the sample is restricted to observations after the conclusion of the MAC abatement initiative, whereas column (5) shows the correlation for a sample restricted to Minneapolis grids. All standard errors are heteroskedasticity robust.

Table 3: Complaint Effect on Home Values

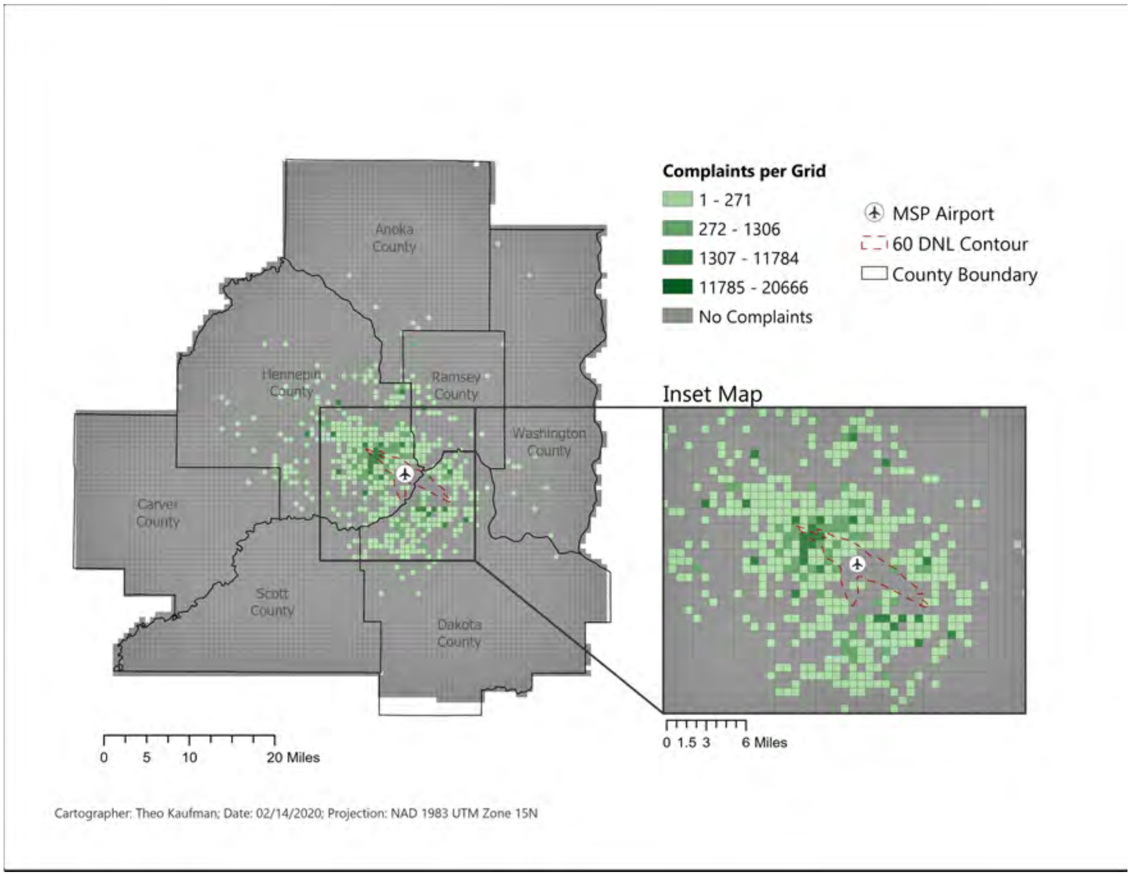
| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| ln(Local Complaints) | -0.005 | -0.005 | -0.014 | -0.011 | -0.011 |
| | (0.001) | (0.001) | (0.002) | (0.002) | (0.002) |
| ln(Local Complaints) X $\delta_{it}$ | | 0.017 | 0.018 | 0.018 | 0.008 |
| | | (0.002) | (0.002) | (0.002) | (0.002) |
| ln(Local Complaints) X | | | 0.001 | 0.001 | 0.001 |
| Distance to MSP Airport (km) | | | (0.000) | (0.000) | (0.000) |
| # of bedrooms | 0.072 | 0.073 | 0.073 | 0.076 | 0.081 |
| | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| # of bathrooms | 0.198 | 0.195 | 0.194 | 0.190 | 0.166 |
| | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| # of fireplaces | 0.175 | 0.172 | 0.173 | 0.176 | 0.150 |
| | (0.003) | (0.003) | (0.003) | (0.003) | (0.003) |
| Year built ('0) | -0.003 | -0.005 | -0.005 | -0.003 | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| ln(Parcel Square footage) | -0.010 | -0.007 | -0.007 | -0.020 | -0.030 |
| | (0.004) | (0.004) | (0.004) | (0.004) | (0.004) |
| ln(BG population) | 0.033 | 0.031 | 0.032 | 0.028 | 0.047 |
| | (0.006) | (0.006) | (0.006) | (0.006) | (0.006) |
| BG population, white (%) | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| ln(Miles to City Center) | | | | -0.123 | -0.065 |
| | | | | (0.006) | (0.019) |
| Constant | 12.308 | 12.538 | 12.549 | 12.637 | 11.894 |
| | (0.176) | (0.171) | (0.171) | (0.169) | (0.192) |
| Month FE | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y |
| Community FE | Y | Y | Y | Y | N |
| Grid FE | N | N | N | N | Y |
| N | 34,340 | 37,477 | 37,477 | 37,477 | 37,475 |
| adj. $R^2$ | 0.64 | 0.64 | 0.64 | 0.65 | 0.69 |
| F stat | 1113.84 | 1202.62 | 1178.27 | 1174.23 | 1053.35 |

Notes: This table presents the effect of noise complaints on home values. For the first specification the sample is restricted to Minneapolis home sales outside of the MSP noise contour plots. The final four specifications include the full sample of Minneapolis home sales from 2006 to 2017. All standard errors are heteroskedasdicity robust.

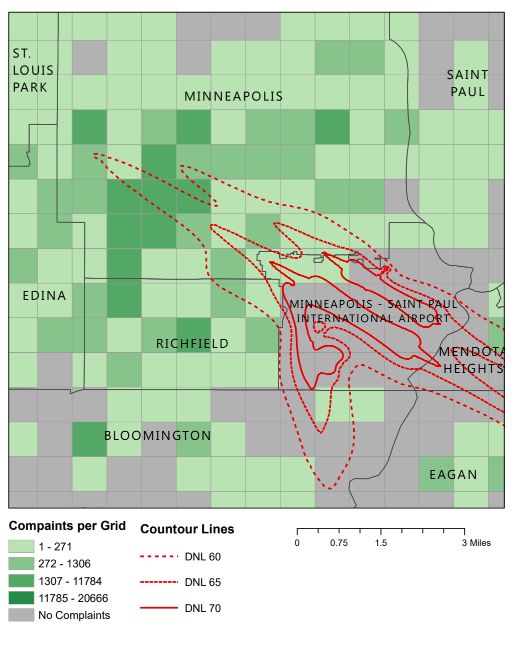
Table 4: Complaint Effect on the # of Sales and Duration Between Repeat Sales

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Dependent Variable | # of Sales per Grid-Year | | # of Sales per Home | | Months btw. Repeat Sales | |
| ln(Local Complaints) | 1.096 | 1.265 | 0.001 | 0.003 | | |
| | (0.134) | (0.161) | (0.001) | (0.002) | | |
| ln(Local Complaints) $\times \delta_{it}$ | | 0.882 | | -0.005 | | |
| | | (0.501) | | (0.002) | | |
| $\Delta$ Local complaints between repeat sales | | | | | 0.002 | 0.001 |
| | | | | | (0.001) | (0.000) |
| $\Delta$ Local complaints $\times \delta_{it}$ | | | | | | 0.001 |
| | | | | | | (0.001) |
| House Characteristics | N | Y | N | Y | N | Y |
| Neighborhood Controls | N | Y | N | Y | N | Y |
| Month FE | N | N | N | N | N | Y |
| Year FE | N | Y | N | N | N | Y |
| Community FE | N | Y | N | Y | N | Y |
| Unit of observation | Grid-Year | | House | | House-Year-Month | |
| N | 1,806 | 1,806 | 38,005 | 37,658 | 11,599 | 11,552 |
| adj. $R^2$ | 0.04 | 0.34 | 0.00 | 0.02 | 0.01 | 0.23 |
| F stat | 67.35 | 28.45 | 1.27 | 38.68 | 11.67 | 419.42 |

Notes: This table presents the effect of noise complaints on the number of home sales per grid per year (columns (1)-(2)), the number of sales per home (columns (3)-(4)), and the duration between repeat sales (columns (5)-(6)). All standard errors are heteroskedasdicity robust.

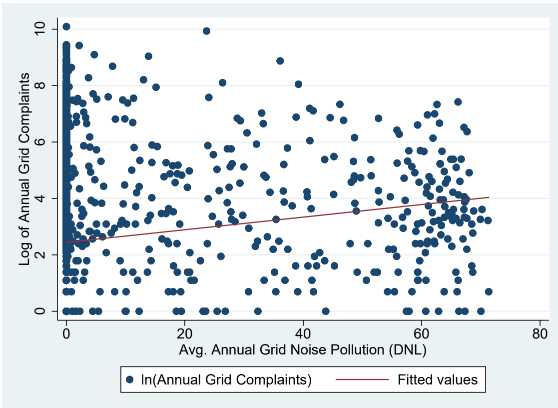



1.1: Seven MN counties surrounding MSP

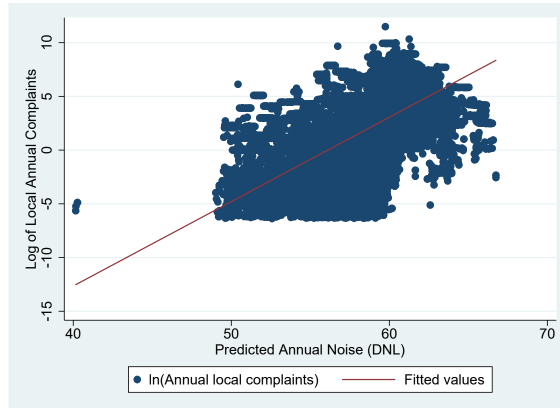



1.2: Minneapolis

Figure 1: 2016 Noise Complaints relative to Noise Contours surrounding MSP




2.1: Grid Complaints & Avg. Grid Noise Pollution




2.2: Local Complaints & Predicted Noise Pollution

Figure 2: Annual Noise Complaints and Noise Pollution

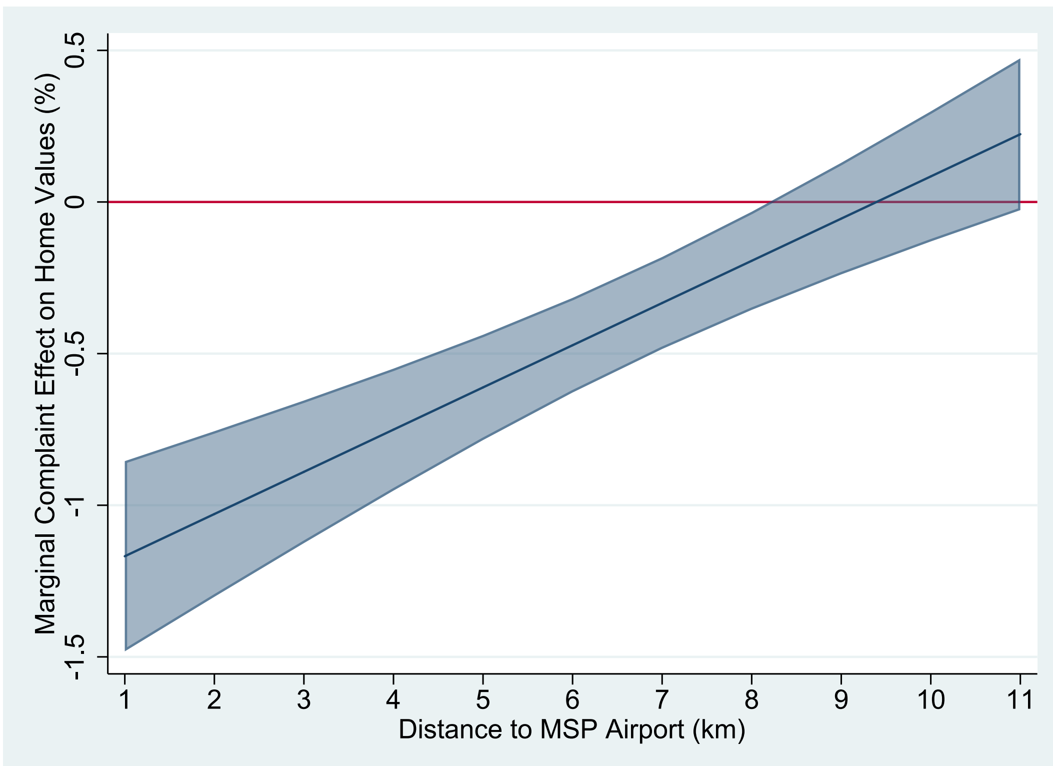



Figure 3: Marginal Noise Complaint Effect on Home Values over Distance from MSP

# A Appendix

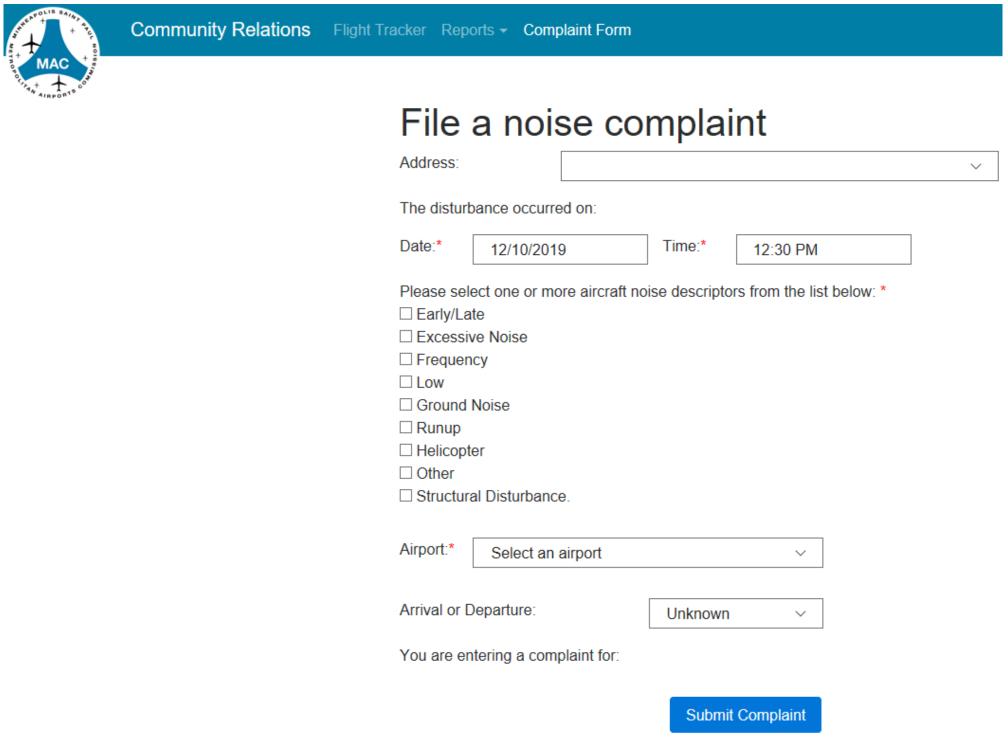
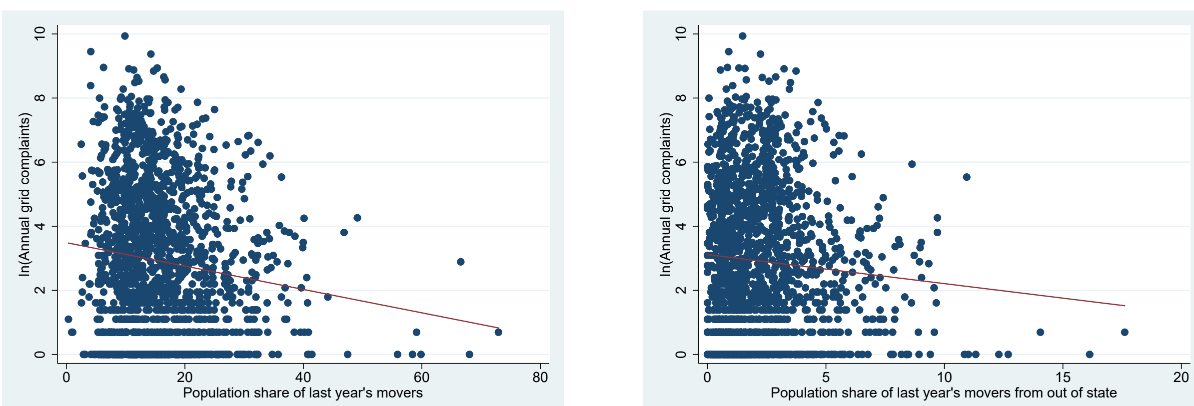



Figure 4: Noise Complaint Template




5.1: All Movers within past Year

5.2: Out-of-State Movers within Past Year

Figure 5: Annual Noise Complaints and Population Share of Movers

Table 5: Model Comparison

| | (1)<br># of<br>Observations | (2)<br>Log-<br>Likelihood | (3)<br>Degrees of<br>Freedom | (4)<br>AIC | (5)<br>BIC |
|---|---|---|---|---|---|
| OLS | 88824 | -602,320 | 22 | 1,204,684 | 1,204,891 |
| PRM | 88824 | -3,473,113 | 22 | 6,946,269 | 6,946,476 |
| NBRM | 88824 | -37,330 | 23 | 74,707 | 74,923 |
| ZINB | 88824 | -34,615 | 36 | 69,303 | 69,641 |

Notes: This table presents a model comparison between the ordinary least squares (OLS) estimator and the three count models, including the Poisson (PRM), Negative Binomial (NBRM) and Zero-Inflated Negative Binomial (ZINB) estimators. The relevant statistics include the log-likelihood, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) and are based on the full model specification given by Equation (1). For the calculation of BIC we assume that N equals the number of observations. The conclusions of the model comparison hold if we assume N equals the number of clusters (7402 grids) instead.

## A.1 Hedonic Contour-based Noise Effect Estimates

The typical hedonic model regresses home sale prices on annual contour noise levels and a host of control variables commonly used in the literature. Similar to Friedt and Cohen (2021), the identification of the traditional aircraft noise pollution effect on home values is based on the differentiation of noise discounts across abatement eligible and ineligible properties. Friedt and Cohen (2021) provide a detailed discussion about the potential issues of reverse causality between home values and aircraft noise and show that noise abatement provides a natural strategy to identify the causal relationship between these two variables. In short, if homeowners do not consider aircraft noise a disamenity, but instead reverse causality leads lower home values to cause greater aircraft noise pollution, then noise insulation should add no value to a home. Consequently, the interaction term between contour noise and abatement eligibility should be insignificant if aircraft noise is truly not a costly disamenity. A positive abatement eligibility effect, however, speaks to the contrary, and would suggest the causality runs from aircraft noise pollution to lower home values.

Consistent with this strategy and previous estimates (Friedt and Cohen 2021), here the aircraft noise pollution measured via noise contours causes a statistically and economically significant reduction in sale prices among Minneapolis homes located within these contour curves, while abatement eligibility offsets this noise discount. The coefficient estimates are presented in Table 6 and build from a parsimonious specification (column (1)) to the preferred model as described by Equation (2) (column (5)). While the parsimonious noise effect estimates (Table 6, columns (1) through (3)) are large, they tend to decline with additional control variables, and the preferred parameter estimates presented in column (5) of Table 6 agree with much of the previous literature (see, for example, Boes and Nüesch (2011)). Specifically, the estimates suggest a one dB DNL noise increase reduces home values by 0.5% for abatement ineligible homes (column (5)). As expected, the number of bedrooms, bathrooms, and fireplaces exert a positive influence on sale prices. In contrast, newer homes tend to command lower values, which may be indicative of the fact older Minneapolis homes are located in more desirable neighborhoods near the MSP airport.

Abatement eligibility offsets the adverse noise effect. In fact, for every one dB DNL increase in contour noise, abatement eligibility reduces the noise discount by 0.1 percentage points. This aligns with the implementation of the noise abatement program, where the amount of sound insulation subsidies increased with greater aircraft noise pollution. Eligible homes at the 64 dB DNL, for example, received the full abatement package, valued around $30,000 to $40,000, while an eligible property experiencing 60 dB DNL according to the 2007 forecasted contour curves received a partial insulation package valued at around $14,000 (Metropolitan Airports Commission 2017). According to the coefficient estimates in the present study, the former type of home experienced a full offset of the noise discount, while the latter was only partially reimbursed.

Table 6: Noise Pollution Effect on Home Values

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Noise pollution (DNL) | -0.031 | -0.037 | -0.020 | -0.005 | -0.005 |
| | (0.003) | (0.003) | (0.003) | (0.002) | (0.002) |
| Noise pollution (DNL) $\times \delta_{it}$ | | | 0.003 | 0.001 | 0.001 |
| | | | (0.000) | (0.000) | (0.000) |
| # of bedrooms | | | | 0.088 | 0.087 |
| | | | | (0.008) | (0.007) |
| # of bathrooms | | | | 0.158 | 0.151 |
| | | | | (0.008) | (0.008) |
| # of fireplaces | | | | 0.139 | 0.129 |
| | | | | (0.007) | (0.007) |
| Year built | | | | -0.008 | -0.008 |
| | | | | (0.001) | (0.001) |
| ln(Parcel Square footage) | | | | 0.189 | 0.190 |
| | | | | (0.028) | (0.028) |
| ln(BG population) | | | | | 0.030 |
| | | | | | (0.017) |
| BG population, white (%) | | | | | 0.005 |
| | | | | | (0.000) |
| Constant | 14.549 | 15.111 | 13.931 | 26.529 | 24.972 |
| | (0.161) | (0.171) | (0.222) | (1.036) | (1.060) |
| Month FE | N | Y | Y | Y | Y |
| Year FE | N | Y | Y | Y | Y |
| N | 3,083 | 3,083 | 3,083 | 3,074 | 3,074 |
| adj. $R^2$ | 0.03 | 0.08 | 0.10 | 0.61 | 0.62 |
| F stat | 147.32 | 15.32 | 18.16 | 142.33 | 148.07 |

Notes: This table presents the effect of contour-based noise pollution on home values. Across all specifications the sample is restricted to Minneapolis home sales within MSP noise contour plots from 2006 to 2017. All standard errors are heteroskedasdicity robust.

# Notes

[1]Schlenker and Walker (2015) find that heart and pulmonary patient health care treatment costs rise by over half of a million dollars for a one-standard deviation in air pollution near airports in California.

[2]The majority of the literature on house price impacts of airport noise focuses on measured noise levels, opposed to complaints. In the U.S. for instance, Cohen and Coughlin (2008) consider how noise near the Atlanta airport impacted house prices, and they find that single-family residential properties within the 65 dB noise contour sold for approximately 20 percent less than those properties in a buffer zone of 55 dB or less. There are a vast number of other hedonic studies that follow similar approaches, such as Espey and Lopez (2000), who focus on the Reno-Sparks airport. Nelson (2004) is a meta-analysis that integrates many hedonic airport noise studies, and he finds that among over 20 different studies, the country in which the airport is located, and the model specification are the most important determinants of the noise discount. More recently, Friedt and Cohen (2021) consider a hedonic model of the Minneapolis/St. Paul airport, with an identification strategy based on soundproofing eligibility. They find properties ineligible for abatement experienced a 2 percent discount over a 3-year period before their sale, while those properties eligible for abatement did not experience any significant discount. Using spatial econometric techniques, Affuso et al. (2019) find slightly less than a $5,000 discount per decibel of noise near the airport in Memphis, TN.

[3]The U.S. airport noise findings are somewhat robust in studies of other countries. In Europe for instance, Boes and Nüesch (2011) find that property values fall by approximately 0.5% for every one-decibel increase in noise near the Zurich, Switzerland airport. Mense and Kholodilin (2014) focus on flight paths opposed to the measured noise levels, and they find residential properties within newly announced flight paths near the airport in Berlin, Germany experienced price decreases in the range of 8%-13%.

[4]The day-night average sound level (DNL) noise metric reflects a person's cumulative exposure to sound over a 24-hour period and the threshold represents the DNL on the average day of the year on the basis of annual aircraft operations. It is the standard noise metric used by the FAA.

[5]These Lden and Lnight thresholds represent the A-weighted long-term average sound levels determined over all day, evening, and/or night periods of a year. The underlying noise metric is defined by the International Organization for Standardization (ISO) in ISO 1996-2: 1987.

[6]These thresholds are based on the ISO 1996-2: 1987 noise metric.

[7]Baumol et al. (1988) indicate that with environmental disamenities in general, compensation should be provided only to homeowners who have experienced additional exposure to the disamenity after the time of the home purchase. This is because the level of disamenity that was present at the time of the home purchase was already factored into the purchase price. Baumol and Oates (1988) therefore implies, in the context of airport noise exposure near MSP, that there should be limitations to the extent to which homeowners should be compensated including sound proofing insulation.

[8]One potential concern is that residents may engage in strategic behavior, such as complaining more in order to receive more abatement. While the MAC has established this complaint registry in an effort to "log, monitor and analyze concerns of airport neighbors" (Metropolitan Airports Commission 2018), there is no explicit promise of restitution or even changes in airport operations in response to these complaints. Given the magnitude of the number of complaints and the specifics required to make each complaint (i.e. date and time of flight), it seems unlikely that complaining residents engage in such strategic behavior.

[9]Since these characteristics, including contour noise, are not originally reported at the grid level, we compute these statistics using spatially weighted averages of the relevant variables. In the next section, we provide further details on these calculations.

[10]Alternatively, one may use the complaints per capita as the dependent variable and exclude grid-level population as an independent regressor. The results are robust to this alternative model specification.

[11]The results do not depend on this adjustment. All estimates are qualitatively and quantitatively consistent when using contemporaneous noise pollution instead.

[12]A careful definition of the local measure of noise complaints and its mapping against house sales is provided in the next section.

[13]For the years of 2007 through 2009, MSP contours only distinguish aircraft noise in 5 dB DNL intervals at 60 dB, 65 dB, 70 dB, and 75 dB DNL. For all other years, the MAC produces MSP contours differentiating aircraft noise pollution at the one dB DNLs between 60 dB and 80 dB.

[14]Take for example a grid with a large volume of heavily concentrated annual complaints and a home sale within the same grid that falls outside of this area. In this case, we would falsely attribute significant noise complaints to

this property, while in reality this transaction was perhaps less affected by the indicated noise annoyance. Similarly, a complaining homeowner may be located in a grid with few noise complaints overall, but still experience significant aircraft noise pollution in a spatially concentrated but small area relative to the grid. Under both of these circumstances, our estimate of the true noise pollution effect on home values would be biased. The direction of the bias tends downwards in first case and upwards under the second scenario.

[15]Reassuringly, all estimates are quantitatively and qualitatively consistent when limiting the number of complaints to the specific grid a given property is located in.

[16]To ensure the arm's length property of our data, we exclude outliers in the top and bottom 1% of sale price distribution. Specifically, we exclude 14 transactions valued above $3,000,000 and four transactions valued below $10,000. Our findings do not depend on these exclusions.

[17]Of course, this is a very imprecise measure of actual aircraft noise pollution. Even in an experimental setting (i.e. a vacuum) noise does not dissipate linearly over distance. This assumption is even more inaccurate in a city environment with many obstacles blocking sound from traveling. And, this is precisely the reason why it is inadvisable to rely on a noise pollution measure based on extrapolated noise contour plots to quantify noise-induced home price discount. Instead, we use this measure to merely show the correlation between contour-based noise pollution as well as noise complaints.

[18]While these results are robust to the exclusion of county fixed effects, more disaggregated spatial fixed effects at the grid level lead to non-convergence of the ZINB estimator.

[19]These estimates are contrary to the findings of some of the previous literature, vary across the contour-based and complaint-based estimations, and point to the potential influence of some unobserved housing and/or neighborhood characteristics. In Minneapolis, for example, older homes with smaller lot sizes are often located in more desirable neighborhoods near downtown. Indeed, adding a control variable for distance to the city center as well as more disaggregated neighborhood fixed effects at the grid level renders the coefficient on the year a home was built statistically insignificant (see column (5) of Table 3).