Valuing Noise Pollution: Evidence from Flight Path Changes*

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December 19, 2025

Abstract

On September 18, 2014, the Federal Aviation Administration implemented new arrival and departure paths to Phoenix Sky Harbor International Airport. Overnight, aircraft noise increased in some residential neighborhoods and decreased in others. These changes occurred with no advance warning. We leverage this shock to provide causal evidence on the value of noise pollution. Our hedonic design uses data on houses that were sold both before and after the shock to identify households' willingness to pay—through housing prices—to reduce noise pollution. We find robust evidence that a one decibel increase in noise caused property values to decline by 1.2%.

*We are grateful for helpful comments and suggestions from Josh Abbott, Kelly Bishop, Tamma Carleton, Olivier Deschenes, Jackson Dorsey, Jacob French, Karen Fisher-Vanden, Renata Gaineddenova, Michael Hanemann, Danae Hernandez-Cortes, Akshaya Jha, Namrata Kala, Cathy Kling, Chris Knittel, Kailin Kroetz, Bryan Leonard, Alvin Murphy, Spencer Perry, Dan Phaneuf, Ivan Rudik, Edson Severinini, Joe Shapiro, Rich Sweeney, and Chris Timmins. We also thank seminar and workshop participants at Arizona State University, UC Berkeley EEE Summer School, Camp Resources, the Urban Economics Association Meeting, and the Southern Economics Association Meeting. Finally, we thank the City of Phoenix Aviation Department for sharing flight path data. This paper originated as a dissertation essay in Mandia (2024).

1 Introduction

Noise is often called the "forgotten pollutant" because it receives relatively little scientific and regulatory attention despite being associated with a wide range of negative health outcomes (Murphy and King, 2022). But people who are affected by noise find it hard to forget. According to the 2023 American Housing Survey, 20% of US households are bothered by street noise, and 5% say it disrupts their sleep. Since people are free to move, it is natural to expect that residential sorting will cause spatial variation in noise to be capitalized into property values. Indeed, hedonic property value studies consistently report that housing prices are negatively associated with noise. However, it has been historically difficult to develop causal evidence on how much households are willing to pay to reduce noise. We fill this knowledge gap by applying causal inference techniques for hedonic estimation to an unprecedented shock to noise pollution.

Phoenix Sky Harbor International Airport (PHX) is among the busiest airports in the United States, located near the center of one of its most populous cities. On September 18, 2014, aircraft noise in surrounding neighborhoods changed *suddenly*, *substantially*, and *unexpectedly*. The change was caused by the Federal Aviation Administration's (FAA) decision to redesign flight paths to and from PHX using a new satellite-based navigation system. The FAA made similar changes at major airports across the U.S. during the 2010s, but its implementation at PHX was unique. Incredibly, the FAA did not warn the public or Phoenix government officials. So the change in noise came as a complete shock to the housing market. Overnight, some neighborhoods became much noisier while others became quieter.

We use this shock to identify how much households are willing to pay to reduce noise pollution. Our research design is a quasi-experimental adaptation of the hedonic repeat sales estimator, which was originally developed to study changes in road noise (Rosen, 1974; Palmquist, 1982). We start by using administrative data on nearly 900,000 flight paths before and after the FAA policy shock to construct state-of-the-art measures of on-the-ground noise. We link these data to single-family property sales in the Phoenix metropolitan area. Then we use hedonic price functions to estimate how much households are willing to pay to reduce noise. Our main specification is a fixed-effects regression that uses properties sold both before and after flight paths changed. We identify the capitalization rate from within-property changes in noise that were caused by the FAA policy.

We find that a 1 decibel increase in noise above the U.S. Environmental Protection Agency's recommended 55-decibel limit (US Environmental Protection Agency, 1974) caused property values to decline by 1.2%. Our repeat sales estimator allows the shape of the equilibrium hedonic price function to evolve flexibly over time (Kuminoff and Pope, 2014; Banzhaf, 2021) and we show that our main finding is robust to a wide variety of alternative specifications. Our estimates imply that the FAA policy modified single-family property values by $374 million, which is more than twice as large as the value of fuel saving and reduced carbon emissions that the FAA used to justify changing flight paths at PHX. This underscores the importance of incorporating credible measures of the value of noise into cost-benefit analyses of transportation policies.

Our study extends literature on the demand for local public goods by providing the first causal evidence on how much households are willing-to-pay—through housing prices—to reduce noise pollution. Since Palmquist (1982), numerous studies have shown that higher noise is conditionally associated with lower prices, and some have provided arguably causal evidence on capitalization effects of transportation projects (e.g. McMillen, 2004; Pope, 2008; Boes and Nüesch, 2011; Ahlfeldt et al., 2019; Klaiber and Morawetz, 2021; Cohen et al., 2023; Moretti and Wheeler, 2025). However, compared to other public goods such as air pollution and school quality, it has proven difficult to (1) identify capitalization effects that fully isolate noise from co-generated amenities, and (2) identify capitalization effects that reveal buyers' willingness-to-pay to reduce noise. Our hedonic design accomplishes both tasks by providing the first estimates that simultaneously overcome three key challenges.

The first challenge is that noise is typically co-generated with other amenities. For example, roads that generate noise pollution also generate air pollution and light pollution for nearby residents, while simultaneously reducing their travel times to job locations. Similarly, expansions, closures, and retrofits of airports and roads simultaneously change noise and urban connectedness. The difficulty in fully observing and controlling for co-generated amenities makes it difficult to isolate the capitalization effect of noise from other utility-relevant aspects of transportation infrastructure (Brinkman and Lin, 2024). Our study overcomes this challenge by using changes in noise that are decoupled from co-generated amenities.

Second, spatial variation in noise pollution may affect long-run neighborhood dynamics through residential sorting. For example, if higher-income households sort themselves into quieter neighborhoods, and then vote to raise property taxes to fund public education and preserve open space, then quieter neighborhoods may evolve to have better schools and parks (Heblich et al., 2021). Over decades, the endogenous production of public goods can intensify the omitted variable threat to identification. We overcome this threat by using properties that were sold both before and after flight paths changed to measure the housing market's short-term response to noise shocks that literally happened overnight.

The final challenge is that policy-induced changes in noise pollution are virtually always anticipated. This makes it difficult to interpret causal estimates for capitalization effects as revealed preference measures of what households are willing-to-pay. The difficulty is that pre-event prices embed buyers' latent expectations about future changes in noise (Bishop and Murphy, 2019). This channel poses a threat to identifying willingness-to-pay from changes in noise that are caused by *pre-announced* transportation projects or any other scenario where a change in noise was at least partly anticipated. We overcome this challenge through our focus on a noise shock that was uniquely unexpected. Homebuyers and sellers in Phoenix had no reason to expect that aircraft noise would change in the future. While the FAA modified flight paths at major airports across the U.S. during the 2010s, PHX was among the first airports to be treated, and its treatment was distinguished from other airports by the FAA's failure to provide advance warning.[1] This unique policy context distinguishes our study from all prior work on noise pollution and motivates our econometric design.

2 Policy Context

2.1 Next Generation Air Transportation System

The FAA is responsible for air traffic control and navigation in the United States. In 2004, the FAA released the "Next Generation Air Transportation System" plan to modernize air travel, commonly known as "NextGen" (US Joint Planning and Development Office, 2004). A key feature of NextGen was performance-based navigation, a set of satellite-based technologies that enable planes to navigate more efficiently. These technologies enable planes to fly more direct routes and allow multiple flight paths to be consolidated into common airspace. In principle, performance-based navigation can be used to design flight paths that reduce fuel consumption, carbon emissions, and residential exposure to aircraft noise.

During the 2010s, the FAA incrementally implemented NextGen flight paths at major airports. This significantly redistributed air traffic. Concentrating flight paths reduced the number of neighborhoods that were exposed to aircraft noise. However, neighborhoods located under the newly concentrated flight paths were exposed to more noise.[2] These changes occurred overnight. Moreover, in the special case of PHX, the changes came as a complete surprise to residents and local

[1] In a concurrent study, Allroggen et al. (2025) estimate capitalization effects of the FAA policy for selected airports other than PHX. Their findings complement ours by showing that the capitalization effects extend beyond PHX. The original version of our paper—Mandia (2024)—provides additional background on the unique policy history at PHX.

[2] The San Francisco International Airport describes the change as follows: "Prior to 2015 when aircraft used ground-based radar navigation, planes flew in so-called six-lane highways in the sky. Now the six-lane highways have become one-lane highways. People who live in neighborhoods located under these major flight routes have experienced an increase in air traffic since 2015. That means more noise."(San Francisco International Airport, 2025).

government officials.

2.2 Quasi-Experimental Variation in Aircraft Noise

PHX is the largest airport in Arizona and among the busiest airports in the United States.[3] NextGen flight paths were implemented on September 18, 2014. Figure 1 provides a representative example of how flight paths changed. The solid red lines show departure paths for all flights during a sample week before NextGen; the dashed blue lines show departure paths during a sample week after NextGen was implemented. The NextGen routes were visibly concentrated. Strikingly, the FAA eliminated air traffic above some neighborhoods and increased it above others. Further, the size of the increase varied. Some neighborhoods under the NextGen routes had previously been exposed to a smaller amount of air traffic; other neighborhoods had no prior exposure.

The resulting changes in noise pollution came as a shock to Phoenix residents and government officials. This is because the FAA did not prepare an environmental impact statement, it did not seek public comment on the modified flight paths, and it did not warn city leaders that PHX flight paths were scheduled to change. Airport officials stated: "*These changes took place with no input from or notice to the community*" (City of Phoenix Aviation Department, 2021). The FAA's advance communication with the City of Phoenix was limited to low-level staffers who were not authorized to represent the city and did not convey the information to city leaders (US Appeals Court, 2017). Indeed, this communication breakdown served as the basis for a successful lawsuit.

After flight paths changed, noise complaints surged. For example, 24,243 complaints were filed in 2015 compared to just 220 in 2013 (City of Phoenix Aviation Department, 2018). In 2015, the City of Phoenix and residents of a neighborhood located under the new western flight paths sued the FAA to reinstate

[3] The FAA classifies PHX as one of 30 "large hubs", each of which receive more than 1% of U.S. passenger enplanements.

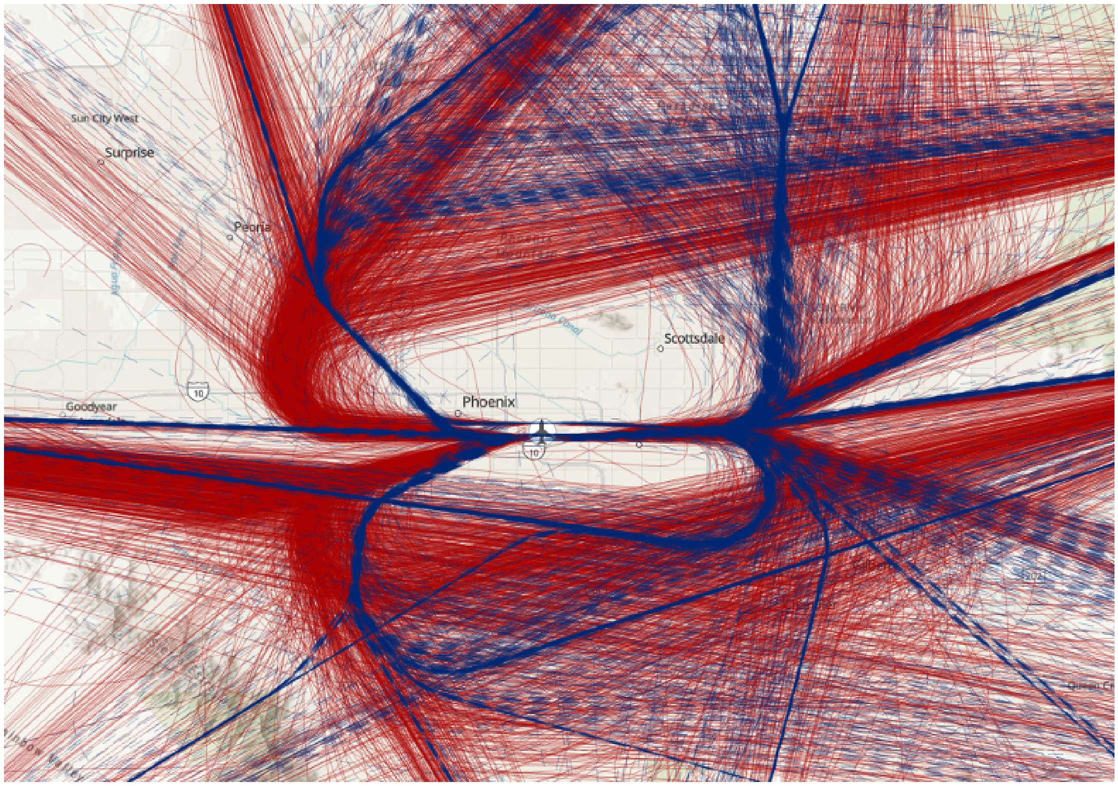

Figure 1: Sample flight paths before and after NextGen

Note: Solid red lines show the old (dispersed) flight paths during a representative week before NextGen: April 3-9, 2011. Dashed blue lines show the new (concentrated) flight paths during a representative week after NextGen: April 3-9, 2016.

the old flight paths. The lawsuit was ultimately decided in 2017 by a U.S. Court of Appeals ruling in favor of the plaintiffs (US Appeals Court, 2017).[4] This was an unexpected, precedent-setting outcome; it was the first time a court had struck down FAA NextGen flight procedures on environmental grounds (Kaplan Kirsch, 2017). The FAA responded by realigning the western flight paths along pre-NextGen routes in March 2018, and starting a long-term process to reconsider the eastern flight paths.

Three features of Phoenix's unique history with NextGen guide our strategy for estimating households' willingness-to-pay to reduce noise. These features also

[4]The court ruled that the FAA's approval of the new routes was arbitrary and capricious, violating the National Historic Preservation Act, the National Environmental Policy Act, the Department of Transportation Act, and the FAA's Order 1050.1E.

distinguish our study from prior research on noise pollution. First, the changes in noise were decoupled from co-generated amenities such as flight volume and distance to PHX.[5] We leverage this feature to help isolate variation in noise. By contrast, most prior hedonic studies of noise pollution used variation in noise that was coupled with on-the ground amenities. This includes studies using spatial variation in noise caused by roads and airports (e.g., McMillen, 2004; Von Graevenitz, 2018) as well as studies using temporal variation caused by expansions, closures, or retrofits of roads and airports (e.g., Palmquist, 1982; Cohen et al., 2023; Moretti and Wheeler, 2025).

Second, the changes in noise were completely unexpected. Importantly, this allows us to overcome the difficulty with interpreting capitalization effects as measures of willingness-to-pay when forward looking households have latent expectations for future amenity levels (Bishop and Murphy, 2019). This feature differentiates our design from Boes and Nüesch (2011), which examined how the prices of rental properties near the Zurich airport were affected by a change to flight paths that had long been contested by German and Swiss authorities. Further, our utilization of an actual, highly salient change in noise differentiates our design from Pope (2008), which measured capitalization of an information treatment that increased the salience of pre-existing noise for homebuyers.

Finally, the court-ordered reversal of PHX's western flight paths in 2018 was unexpected but *not* quasi-random. As noted above, it resulted from a lawsuit filed by residents of a particular neighborhood. The endogeneity of this outcome creates potential for confounding from correlation between neighborhood amenities and the subsequent changes in noise. Therefore, we focus on a 9-year period that is approximately centered on the shock to flight paths in 2014 and ends before their partial reversal in 2018.

[5] Appendix Figure B.1 shows that noise complaints surged after NextGen, while flight volume was essentially unchanged.

3 Data

3.1 Noise Pollution: Measurement

The intensity of noise perceived by the human ear is commonly defined on a logarithmic A-weighted decibel scale (dB). Various indices have been developed to integrate the duration and intensity of noise into measures of average exposure over time. The US Environmental Protection Agency (EPA) and the FAA typically measure aircraft noise using the Day Night Average Sound Level index (DNL). It is a temporal average decibel measure of instantaneous aircraft noise.

Federal regulation of noise started with the Noise Pollution and Abatement Act of 1972. The EPA identified a DNL of 55 dB as providing an adequate margin of safety for avoiding annoyance and interference with outdoor activities in residential areas (US Environmental Protection Agency, 1974). The Federal Aviation Noise Abatement Policy subsequently established a DNL of 65 dB as the threshold for "significant" exposure. These guidelines are often used by federal, state, and local agencies to inform zoning rules and noise disclosure laws (Pope, 2008).[6]

Noise differs from other amenities like air quality, water quality, and temperature in that ambient noise is not tracked by an extensive network of government-operated monitoring stations. We filled this data gap for the Phoenix metropolitan area by using best practices for measuring discernible variation in on-the-ground aircraft noise. The remainder of this section provides a high-level summary of our approach, which we explain in detail in Appendix A.

We started by obtaining data from the City of Phoenix Aviation Department on the universe of flights arriving and departing PHX during one week each month from 2010 to 2019.[7] These data provide a representative sample of air traffic before and after NextGen. The data describe 888,403 flights. Each flight path is characterized by a 3D polyline measuring its latitude, longitude, and altitude

[6] A sound level of 65 dB is similar to normal speech at a distance of three feet. Federal land use guidelines set a DNL of 65 dB as the threshold for residential land use compatibility.

[7] The Aviation department provided data from the 3rd through the 9th of each month.

throughout the flight.

Next, we used the FAA's Aviation Environmental Design Tool (AEDT) software to convert the distribution of flight paths into DNL measures of on-the-ground noise within a grid centered on the airport and divided into 40,000 quarter-mile cells.[8] The resulting DNL measures describe average noise within each cell before NextGen (Jan 2010 to Aug 2014) and after NextGen (Oct 2014 to Feb 2018).

Finally, we normalized the minimum DNL to 55 dB. The reason for this normalization is that variation in aircraft noise below 55 dB is unlikely to be perceived. In metropolitan areas like Phoenix, ambient noise in residential areas typically ranges from 55 to 65 dB. Within this range, additional transportation noise below 55 dB is commonly believed to have no impact due to the limits of human auditory perception (US Environmental Protection Agency, 1974; US Department of Transportation, 2018).[9] While AEDT software can predict changes below 55 dB, using data on imperceptible changes in low-level noise could bias a hedonic estimator by introducing nonclassical measurement error. Further, we test our normalization in Section 5.2 and find that housing prices are insensitive to changes in noise between 50 and 55 dB, which is the typical range of sound in quiet exurban areas. Appendix Figure B.2 illustrates our final measures for the spatial distribution of aircraft noise before and after NextGen.

3.2 Noise Pollution: Identifying Variation

Our cross-sectional measures of aircraft noise before and after NextGen reflect best practices in the predictive modeling of sound. However, they do not account for

[8] AEDT is the software that the FAA uses to calculate aircraft noise. However, the FAA did not use it to report prospective noise for its flight path changes at PHX. This omission was noted in the city's successful lawsuit.

[9] The difficulty in perceiving aircraft noise below 55 dB follows from the way that aircraft noise and non-aircraft noise interact on the logarithmic decibel scale to determine cumulative noise. For example, suppose that ambient noise *excluding planes* is 60 dB, which is typical for urban areas like Phoenix. If the aircraft DNL is 7 (which is the minimum that AEDT predicts in our study area) then the cumulative noise level *including planes* is 60.00002 dB. In comparison, if ambient noise is 60 dB and aircraft noise is 50 dB then the cumulative noise is still only 60.4 dB.

background noise from roads, trains, and other commercial and industrial activity. These latent features may be simultaneously correlated with property values and aircraft noise, posing a threat to identification. We address this threat by using a repeat sales design that employs property fixed effects to absorb the latent features of each property. Importantly, the fixed effects also absorb latent neighborhood amenities that may be correlated with pre-NextGen noise levels, regardless of whether or not those amenities were endogenously determined by residential sorting prior to NextGen. For example, the fixed effects absorb price effects of local school quality, local pollution, proximity to the city center, transportation infrastructure, and so on. Thus, our repeat sales strategy forces the identifying variation in noise to come from *within-property changes in noise caused by the FAA policy*.

Figure 2 shows the policy-induced changes in noise that we use for identification. The red-shaded area (bounded with a dashed line) shows where noise increased, and the unbounded green-shaded area shows where noise decreased. Darker shading indicates larger absolute changes.

Three features of the data in Figure 2 are particularly helpful for identifying the willingness-to-pay for noise reduction. First, the changes are large, sometimes exceeding 5 dB. Increases of this size are commonly found to trigger widespread complaints and threats of legal action (US Department of Transportation, 2018). Second, the changes in noise are decoupled from changes in co-generated amenities such as airport accessibility and flight volume, as we noted earlier and show in Appendix Figure B.1. Third, the changes vary in both size and direction, providing rich variation to identify capitalization effects.

3.3 Property Sales

More than 90% of the Phoenix MSA population lives in Maricopa county, including all of the area shown in Figure 2. We obtained the universe of residential property sales in Maricopa from 2009 through 2018 from the county Assessor's office. For each transaction, the data describe the sale price, sale date, square footage of living

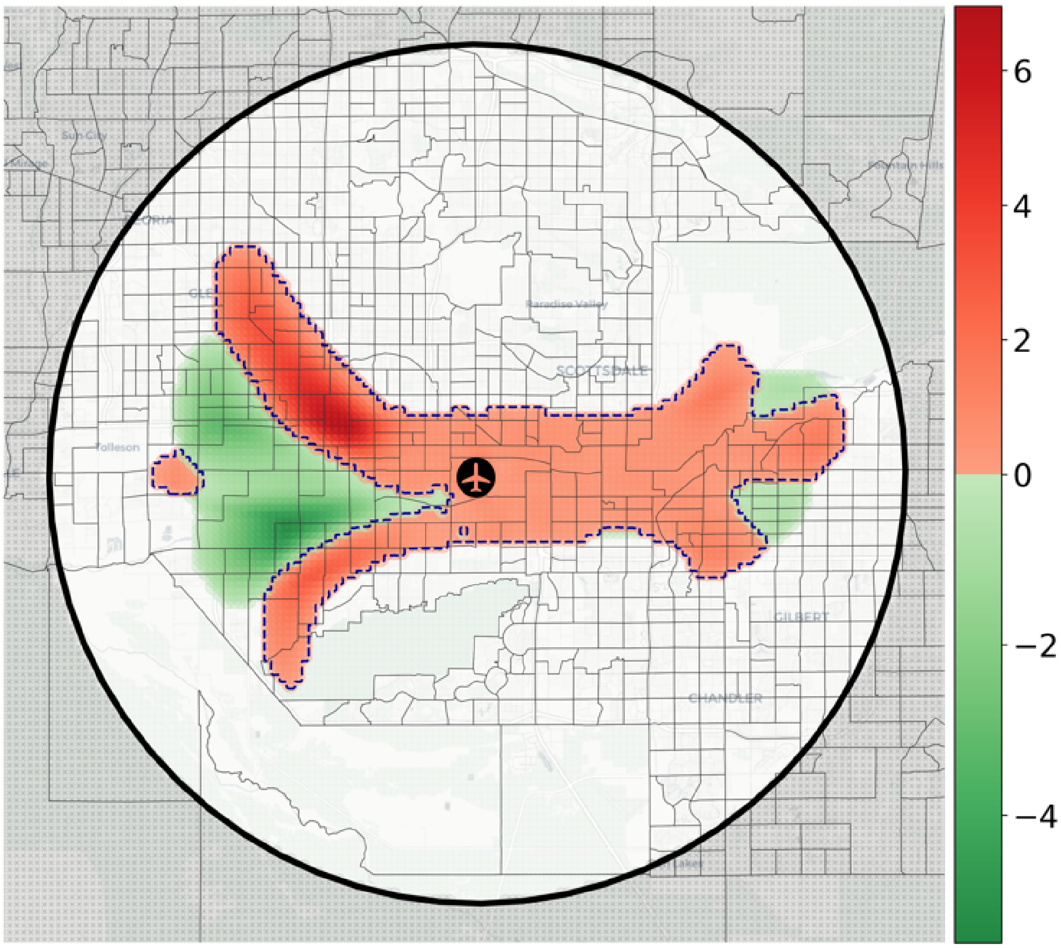

Figure 2: Policy-induced changes in aircraft noise

Note: The map shows changes in the Day Night Average Sound Level index of noise pollution caused by implementation of NextGen flight paths in 2014. Areas where noise increased are shaded in red and bounded with a dashed line. Areas where noise decreased are shaded in green and unbounded. Darker shading indicates larger changes in noise, as shown in the legend.

space, square footage of the lot, number of bathroom fixtures, construction year, whether the house has a pool, heating system type, cooling system type, building materials for the walls and roof, garage type, patio type, whether the property has multiple stories, and whether it is a detached residence or condominium. Then we used each property's latitude and longitude coordinates to match it to a Census tract and aircraft noise pollution before and after NextGen.

We focus mainly on detached single-family houses within 17 miles of PHX (shown by the circle in Figure 2) that were sold between October 2009 and February 2018. We followed best practices in hedonic property value estimation by making a few cuts to standardize the estimation sample (Bishop et al., 2020). Specifically, we dropped 28% of sales that were (i) missing characteristics, (ii) non arms-length sales, (iii) foreclosures, (iv) "flipped" more than once in the same month, or (v) in the top or bottom percentile for square footage, parcel area, bathroom fixtures or sale price. This left us with 252,555 transactions of 192,996 properties, and a subset of 24,010 properties that were sold both before and after NextGen. Appendix B provides summary statistics.

4 Estimation Strategy

Equation (1) shows our main specification for the hedonic price function. We regress the log price of property j sold in month-year t on aircraft noise and other covariates. Noise is uniquely determined by two factors: (i) the grid cell where property j is located and (ii) whether t occurred before or after flight paths changed.

$$ln(price_{jt}) = \beta Noise_{jt} + \gamma X_{jt} + \eta_t + \xi_j + \epsilon_{jt}, \tag{1}$$

The vector X_{jt} includes the property characteristics we listed in Section 3.3 (house size, lot size, pool, wall type, etc.) as well as the Euclidean distance from each property to PHX. We control for distance to the airport because it may provide a distinct transportation amenity. X_{jt} also includes interactions between each property characteristic and an indicator for whether t occurred after NextGen. These interactions flexibly control for changes in the shape of the price function that can otherwise confound identification of willingness-to-pay (Kuminoff and Pope, 2014; Banzhaf, 2021). Finally, we cluster the errors, ϵ_{jt}, at the level of "treatment"; i.e. by noise grid cell before and after NextGen.

We control for seasonality and price trends by adding fixed effects for sale month-by-year (η_t). Finally, ξ_j is a property fixed effect. It absorbs all of the time-constant latent attributes of each property.

Thus, the focal parameter, β, measures the percentage change in property values caused by a 1 dB increase in noise. This effect is identified by within-house changes in aircraft noise over time, conditional on time trends and changes in the shape of the price function. The identifying variation in noise, shown in Figure 2, is derived entirely from the unanticipated changes to flight paths caused by the NextGen policy.

5 Capitalization of Noise Pollution

5.1 Main Results

We find that a 1 dB increase causes property values to decline by about 1.2%. To illustrate the importance of various aspects of our identification strategy, we summarize results from five regressions.

The first column of Table 1 begins with a simple associative regression. It uses data on 252,555 sales of 192,996 properties, most of which were sold only once during the study period. The only covariates are the property characteristics in X_{it}. A one decibel increase in DNL is conditionally associated with a 3.5% reduction in property value.

Column (2) repeats the regression in column (1) after adding fixed effects for year-by-month and Census tract. In this case, the noise coefficient is identified by the NextGen-induced changes in noise, and by cross-sectional variation in noise within Census tracts. Comparing columns (1) and (2) shows that controlling for time trends and unobserved tract features reduces the capitalization effect by nearly two thirds. This decrease is consistent with confounding via correlation between noise and unobserved local amenities.

Columns (3) and (4) repeat the regression in column (2) after splitting properties into two mutually exclusive subsets. Column (3) uses properties that were *not*

Table 1: Main Results - Capitalization of Aircraft Noise

	(1)	(2)	(3)	(4)	(5)
Aircraft Noise (db)	-0.0346***	-0.0126***	-0.0119***	-0.0139***	-0.0121***
	(0.0021)	(0.0023)	(0.0024)	(0.0030)	(0.0036)
FE: year x month		x	x	x	x
FE: Census tract		x	x	x	
FE: property					x
Non-repeat sales only			x		
Repeat sales only				x	x
R^2	0.638	0.874	0.876	0.875	0.942
# transactions	252,555	252,555	197,419	55,133	55,133
# properties	192,996	192,996	168,983	24,010	24,010

Note: The table reports the marginal capitalization effect of a one decibel increase in aircraft noise. The dependent variable is the natural log of house sale price. Standard errors are clustered by noise grid cell by period. There are two periods: before and after flight paths changed. Asterisks denote statistical significance at * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

sold before *and* after NextGen. While some of these properties were sold multiple times, all of their sales occurred either before NextGen or after NextGen. By contrast, column (4) uses the subset of properties that were sold both before *and* after NextGen.

Comparing columns (2), (3) and (4) allows us to assess the external validity of using the repeat sales sample to estimate capitalization effects for the broader market. In principle, the repeat sales sample could be selected on unobserved property characteristics that substantially modify the capitalization effects of noise. However, this is not the case. Both regressions yield capitalization effects that are quantitatively similar to each other, and to column (2).

Finally, column (5) shows our preferred specification. It uses the repeat sales sample to estimate the hedonic fixed effects estimator in Equation (1). Adding property fixed effects forces the capitalization effect to be identified by the NextGen-induced changes in aircraft noise. This modification caused our estimate to decline slightly from column (4) to 1.2%.

5.2 Sensitivity Checks

Table 2 and Appendix Table C.1 summarize alternate specifications. Each alternative is designed to test whether our main specification is confounded by a specific mechanism. We find no evidence of confounding and briefly summarize the results.

Controlling for changes in air pollution. Air traffic generates local air pollution (Schlenker and Walker, 2016; US Department of Transportation, 2024) which is known to matter for property values (Sager and Singer, 2025). This suggests an alternate hypothesis for our results: changes in noise pollution and air pollution are co-generated, but only air pollution matters for property values. To test this hypothesis, we repeat the regression after adding local average concentrations of fine particulate air pollution ($PM_{2.5}$) measured on a 1-km grid during a two-year period before and after NextGen.[10] Column (2) of Table 2 shows that controlling for air pollution yields a capitalization effect of 1.2%, which is nearly identical to our main result (repeated in column (1) for convenience).

Adding condominiums. Hedonic property value studies typically focus on the market for detached single-family housing (Bishop et al., 2020). However, changes in noise pollution could also affect the values of apartments and condominiums. Knowing this effect is necessary to characterize how NextGen affected the broader housing market. Further, the capitalization effect of noise could differ for apartments and condominiums relative to single-family houses, for example, because renters and condo-owners do not own the outdoor portions of their lots where aircraft noise is louder. While we lack data on apartments, we can add condominiums. Column (3) of Table 2 shows that this increases the number of transactions by about 30% but yields a very similar capitalization effect of 1.1% per dB. We conclude that our main result is broadly applicable to Phoenix households.

[10]These data are from Di et al. (2017). Concentrations were measured using an artificial neural network that incorporated satellite measurements, EPA air quality monitoring station records, a chemical transport model, land use data, meteorological data, and other sources. The pre-NextGen data are based on average concentrations in 2012-2013, and the post-NextGen data are based on average concentrations in 2015-2016.

Table 2: Alternate Specifications for the Repeat Sales Regression

	(1)	(2)	(3)	(4)	(5)	(6)
Aircraft Noise (db)	-0.0121***	-0.0118***	-0.0112***	-0.0114***	-0.0109***	-0.0117***
	(0.0036)	(0.0036)	(0.0038)	(0.0036)	(0.0036)	(0.0037)
modification		add PM2.5	add condos	25-mi radius around airport	drop houses < 5 mi from local airports	drop sales after court decision
R^2	0.942	0.942	0.946	0.951	0.940	0.941
# transactions	55,133	55,133	71,704	100,469	44,210	45,059
# properties	24,010	24,010	31,365	44,361	19,154	19,901

Note: The dependent variable is the log transaction price. All specifications include property fixed effects and year x month fixed effects. Column (1) repeats our main specification in Table 1 Column (5) as a benchmark for comparison. Column (2)-(7) modify our main specification as described in the table. Standard errors are clustered by noise grid cell by period. There are two periods: before and after flight paths changed. Asterisks denote statistical significance at * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Expanding the study area. Figure 2 shows that our focus on a 17-mile radius around the airport captures all houses that were treated by the noise shock, as well as surrounding untreated houses. This comparison could be misleading, however, if more distant suburbs are closer substitutes for the treated neighborhoods. However, this is not the case. Column (4) of Table 2 shows that we obtain a similar capitalization effect (1.1% per dB) when we widen our focus to a 25-mile radius that captures most of metropolitan Phoenix and nearly doubles our repeat sales sample.

Excluding local airports. NextGen could have indirectly affected noise around local airports in the Phoenix area due to re-routing of flights within shared airspace.[11] PHX is the main commercial airport, but several smaller airports are used for general aviation and limited commercial travel. While NextGen did

[11] Air traffic above the Phoenix metro area is managed by an FAA facility (Phoenix Terminal Radar Approach Control) that coordinates arrival and departure paths from PHX and other local airports to avoid conflicts. The local airports include Dear Valley, Glendale Municipal, Scottsdale, Falcon Field, Goodyear, Chandler Municipal, and Mesa Gateway.

not directly affect the smaller airports, changes to PHX flight paths could have indirectly caused changes to flight paths at the local airports. Since we lack air traffic data for the local airports, unobserved changes to their flight paths could introduce nonclassical measurement error into our noise measure. To test whether this is likely to confound our estimator, we dropped all houses within five miles of a local airport. Column (5) shows that this reduces our sample by about 20% but still yields a capitalization effect of about 1.1% per dB.

Avoiding anticipatory behavior. As we noted in Section 2.2, NextGen triggered a successful federal lawsuit. The court's August 2017 ruling against the FAA was an unexpected, precedent-setting outcome (Kaplan Kirsch, 2017). However, after the ruling, well-informed buyers could have adjusted their bids to reflect expected future changes in noise that were realized starting in March 2018. As noted earlier, this type of latent anticipatory behavior can undermine welfare interpretation of capitalization effects (Bishop and Murphy, 2019). To test whether our main results are confounded by latent dynamics near the end of the study period, we repeat the estimation after dropping transactions that occurred after the court ruling. Column (6) of Table 2 shows that this continues to yield a capitalization effect of 1.2% per dB.

Adding additional flexibility. To test whether the capitalization rate varies with the level of noise, we divide properties into five-decibel noise bins and estimate effects for each bin. The results yield very similar capitalization rates-per-decibel below 65 decibels from 1.0% to 1.4%. We estimate a higher rate above 65 decibels (2.7%) but this is hardly relevant because only 0.30% of properties are above this threshold. Finally, we repeat the estimation using a lower 50 dB threshold for the minimum perceptible level of aircraft noise—consistent with the level of ambient noise in quiet exurban areas (US Environmental Protection Agency, 1974; US Department of Transportation, 2018). We find no evidence of capitalization for changes in noise below 55 dB. These results are provided in Appendix C.

6 The Value of Reducing Noise Pollution

The FAA reported that implementing NextGen at PHX reduced annual fuel costs by \$3.6 million and annual carbon emissions by 15,000 metric tons (US Department of Transportation, 2015). This corresponds to \$0.6 million in annual climate benefits using the federal government's 2015 social cost of carbon (\$41/ton). Adding the fuel savings and climate benefits reported by the FAA and using the CPI to convert both figures to year 2025 dollars yields an annual benefit just under \$6 million.

To calculate the corresponding change in property value, we focus on 122,160 single-family houses and condominiums that experienced discernible changes in noise.[12] Some of these properties were sold during our study period, but most were not. Therefore, we predict their values in August 2014 (just before flight paths changed) using the regression in column (2) of Table 1.[13] Then we use a capitalization rate of 1.2% per dB to measure the causal change in value.

Our calculation implies that 84,514 properties decreased in value by an average of \$2,880, while 37,646 properties increased in value by an average of \$3,477. In absolute terms, the policy modified single-family property values by approximately \$374 million (2025 dollars). To compare these statistics with the annual benefits reported by FAA, we apply a 4.1% user cost of housing for neighborhoods around the airport (Bishop et al., 2025).[14] This implies an annual rental-equivalent effect on single-family properties of \$15 million.

Thus, the policy's annualized effect on the housing market—via noise pollution—was more than twice as large as its advertised benefits in fuel savings and carbon

[12]This is the subset of all houses within a 17-mile radius of PHX that had changes in aircraft noise with DNL measures over 55 dB before and/or after NextGen.

[13]This regression allows us to predict values for each property in August 2014 using the property's physical characteristics and Census tract. While this specification does not embed a casual coefficient on noise, it is suitable for predicting market value and has an R^2 of 0.87. Note that we cannot use our main repeat sales specification from column (5) of Table 1 to predict the values of houses that were not repeatedly sold because of that specification's reliance on property fixed effects.

[14]Specifically, the 4.1% figure is an average over user cost rates that Bishop et al. (2025) calculate for the Census Public Use Microdata Area (PUMA) containing PHX and six adjacent PUMAs.

emissions. Most of this effect was a wealth transfer. The policy effectively transferred \$130 million in housing wealth from homeowners living in neighborhoods that were made louder to homeowners living in neighborhoods that were made quieter. The policy also caused a net loss in housing value of \$113 million by increasing the number of properties exposed to noise. Finally, using post-NextGen noise levels, we calculate that the Pigouvian tax needed to compensate homeowners for the loss in property value due to aircraft noise above the EPA's 55 dB limit could be paid by imposing a surcharge of approximately \$1.52 per passenger-flight.[15]

In summary, we provided the strongest casual evidence to date on households' willingness to pay—through housing prices—to reduce their exposure to noise pollution. A one-decibel increase in noise above the Environmental Protection Agency's recommended 55-decibel limit caused property values to decline by about 1.2% (or $\$1,964$ dollars for the average single-family property). Our findings underscore the importance of including the value of noise pollution in cost-benefit analyses of transportation projects.

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[15]This calculation is based on multiplying the marginal capitalization effect of noise by the annualized value of each property and its number of decibels over the EPA limit, and then dividing by 32 million annual passenger enplanements at PHX.

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Supplemental Appendices

A Aircraft Noise Measures

A.1 Day Night Average Sound Level Index

The US Environmental Protection Agency, the Federal Aviation Administration, and local regulators typically measure aircraft noise using the Day Night Average Sound Level index (DNL) shown in equation (A.1).

$$DNL = 10 \times log_{10}\left(\frac{1}{24}\right)\left[\left(15 \times 10^{L_d/10}\right) + \left(9 \times 10^{(L_n+10)/10}\right)\right]. \tag{A.1}$$

The DNL is a weighted average decibel measure of instantaneous exposure to aircraft noise. L_d and L_n represent average hourly exposure to aircraft noise during a 15-hour "day" period from 7am to 10pm and a 9-hour "night" period from 10pm to 7am. For example, L_n is measured as:

$$L_n = 10 \times log_{10}\left(\frac{1}{32400}\right)\left[\sum_{s=1}^{32400} 10^{L_s/10}\right], \tag{A.2}$$

where L_s measures noise at second s and there are 32,400 seconds each night. The DNL inflates L_n by 10 dB to account for increased human sensitivity to aircraft noise during night hours when background noise tends to be lower. The DNL is typically first calculated on a daily basis and then reported as an annual average daily measure.

A.2 Flight Path Data

We obtained data from the City of Phoenix Aviation Department on the universe of flights arriving and departing Phoenix Sky Harbor International Airport (PHX) during the second week of each month from 2010 through 2019. Aviation Department officials indicated that these data are representative of PHX air traffic. The data describe 888,403 flights. Each flight path is defined by a 3D polyline measuring its latitude, longitude, and altitude throughout the flight.

A.3 Converting Flight Paths into Noise Pollution

We used the Aviation Environmental Design Tool (AEDT) version 3d to convert the distribution of flight paths into a DNL-decibel measure of on-the-ground noise. AEDT is a software program that the Federal Aviation Administration uses to calculate aircraft noise. We used AEDT to synthesize flight path data into grids describing average aircraft noise in the Phoenix metropolitan area before and after NextGen flight paths were implemented.

AEDT can be used to project a distribution of four-dimensional flight coordinates describing latitude, longitude, altitude, and time into a two-dimensional grid measuring average aircraft noise on the ground during a particular interval. To accomplish this task we first used Python on ArcGIS Pro version 2.8 to divide each flight polyline into 250-meter segments, divided by nodes. Then for each node located within a 50-mile square grid centered on PHX, we extracted the latitude, longitude, AEDT-predicted altitude under normal flight operations, and time. This yielded 140 million coordinates. Next, we used AEDT to convert the distribution of flight-path coordinates into on-the-ground aircraft DNL estimates over the grid. The grid has roughly 40,000 quarter-mile cells, providing a high-resolution measure of noise exposure across the metropolitan area.

To reduce the computational burden of using AEDT to construct the noise grid, we first used a stratified random 10% sample of nodes to construct relative measures of L_d and L_n within each grid cell before and after NextGen. We stratified by: (i) date (before or after NextGen), (ii) flight type (arrival or departure), and (iii) time of day (7am to 5pm, 5pm to 10pm, 10pm to 7am). Then we reweighted the relative measures of L_d and L_n to account for our sampling procedure and derive absolute measures of noise. For example, if the relative DNL in a particular grid cell based on the 10% sample of nodes is 55 dB then the absolute DNL based on 100% of nodes is 65 dB. That is, $10 \times log_{10}(10) + 10 \times log_{10}(10^{(55/10)}) = 10 + 55 = 65$. We used equation (A.1) to combine the resulting absolute measures of L_d and L_n into average measures of DNL during the pre-NextGen period from January 2010 through August 2014 and the post-NextGen period from October 2014 through March 2018. Finally, we assigned these gridded measures of aircraft noise pollution to properties by using each property's latitude and longitude coordinates to match it to the grid cell in which the property is located.

B Additional Data Details

Figure B.1 shows that noise complaints surged after the introduction of NextGen flight paths, while flight volume was essentially unchanged.

Figure B.2 shows our measure for the spatial distribution of aircraft noise before and after NextGen. The map features a 17-mile radius around the airport with noise contours shown as dashed lines at 55, 60, and 65 decibels.

Table B.1 describes the prices and characteristics of the full transaction sample used in Column (1) of Table 1 and the repeat sales sample used in Column (5) of Table 1. We also report year 2014 American Community Survey data for Census tracts on mean household income, percent White non-Hispanic, and percent of households that are homeowners. Comparing the top and bottom panels of the table shows that the two samples are similar in terms of housing prices, physical characteristics, and neighborhood demographics.

Table B.2 summarizes the characteristics of "treated" houses that experienced discernible changes in aircraft noise (positive or negative) due to NextGen and "control" houses that did not. The "treated" and "untreated" houses are located in the shaded and unshaded areas of Figure 2. By "discernible", we meant that noise was above 55 dB before and/or after flight paths changed. The table shows that the median treated properties are moderately less expensive and smaller than

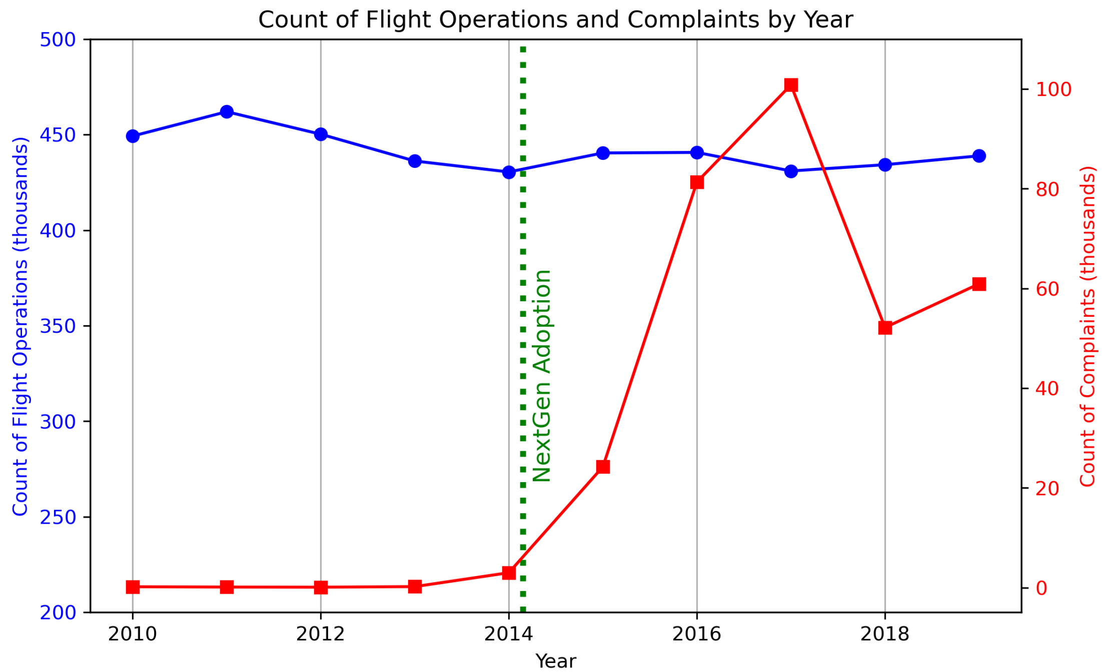
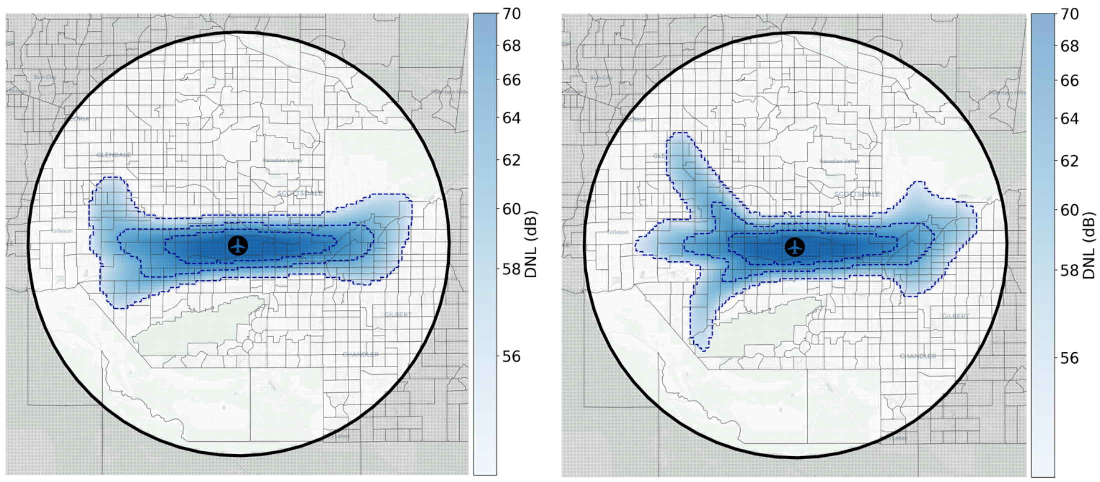


Figure B.1: Noise complaints and Flight Volume, by Year

Note: The red line with square data points shows the number of aircraft noise complaints filed with the City of Phoenix Aviation department by year, measured on the right vertical axis. The blue line with circular data points shows the flight volume at Phoenix Sky Harbor International Airport, measured on the left vertical axis.

the median control property, and located in Census tracts with moderately lower mean household income and moderately lower shares of homeowners and White, non-Hispanic residents. However, the 5th and 95th percentiles show substantial overlap in the distributions of houses and neighborhoods in the treated and control areas.



(a) Noise before NextGen

(b) Noise after NextGen

Figure B.2: Noise levels before and after NextGen

Note: The maps show the Day Night Average Sound Level index of noise pollution around Phoenix Sky Harbor airport before implementation of NextGen flight paths (figure B.2a) and after implementation (figure B.2b). Blue shading indicates the level of noise, as shown in the legend. Dashed contours are drawn at 55, 60, and 65 decibels

Table B.1: Summary Statistics: Single-Family Housing Sales

A: All Sales

	Mean	SD	Min	Max
log price	12.2	0.6	10.5	14.0
sale year	2014.1	2.4	2009.0	2018.0
area (sqft)	1889.9	646.6	729.0	4868.0
lot size (sqft)	8467.7	5079.2	603.0	51829.0
bathroom fixtures	7.5	2.4	2.0	16.0
pool (%)	37.1	48.3	0.0	100.0
distance to PHX (miles)	11.4	3.8	0.8	17.0
age of property	31.7	18.9	0.0	117.8
tract mean income ($)	61390.7	25642.1	9948.0	177778.0
tract % white	79.0	11.4	22.3	99.5
tract % owners	63.1	17.5	0.7	97.7

B: Repeat Sales

	Mean	SD	Min	Max
log price	12.2	0.6	10.5	14.0
sale year	2014.0	2.4	2009.0	2018.0
area (sqft)	1882.7	619.5	736.0	4841.0
lot size (sqft)	8249.3	4465.9	1286.0	51254.0
bathroom fixtures	7.5	2.3	3.0	16.0
pool (%)	40.0	49.0	0.0	100.0
distance to PHX (miles)	11.4	3.9	0.8	17.0
age of property	32.0	19.0	0.0	117.2
tract mean income ($)	61437.9	25136.0	12500.0	177778.0
tract % white	78.9	11.4	37.5	99.5
tract % owners	63.1	17.4	4.8	97.7

Note: Panel A summarizes the full estimation sample used in Columns (1)–(3) of Table 1, containing 252,555 sales of 192,996 properties. Panel B summarizes the repeat-sales sample used in Columns (4)–(5) of Table 1, containing 55,133 sales of 24,010 properties. We suppress the following categorical house characteristics for brevity: heating system type, cooling system type, building materials for the walls and roof, garage type, patio type, and whether the property has multiple stories.

Table B.2: Summary Statistics by Treatment Status

A: Properties with Discernible Changes in Aircraft Noise

	Increase p5	Decrease p5	Increase p50	Decrease p50	Increase p95	Decrease p95
change in noise (db)	0.1	-3.2	0.7	-1.3	3.9	-0.1
log price	10.8	10.7	11.7	11.5	12.6	12.3
sale year	2010.0	2009.0	2012.0	2012.0	2014.0	2014.0
area (sqft)	1031.0	1110.0	1594.5	1684.0	2800.0	3024.0
lot size (sqft)	4500.0	3517.0	7235.0	6660.0	13432.0	11806.0
bath fixtures	3.0	3.0	6.0	6.0	11.0	11.0
pool (%)	0.0	0.0	0.0	0.0	100.0	100.0
distance to PHX (miles)	2.8	6.7	7.7	10.3	13.2	12.3
age of property	3.9	0.8	44.3	12.2	74.6	57.9
tract mean income ($)	22222.0	25375.0	41780.5	43196.0	81750.0	77721.0
tract % white	50.1	44.4	75.9	70.8	91.1	89.8
tract % owners	25.7	25.5	54.7	62.3	83.1	78.0

B: Properties without Discernible Changes in Aircraft Noise

	Control p5	Control p50	Control p95
change in noise (db)	0.0	0.0	0.0
log price	11.1	12.1	13.1
sale year	2010.0	2012.0	2014.0
area (sqft)	1140.0	1802.0	3180.0
lot size (sqft)	4192.0	7532.0	14849.0
bath fixtures	5.0	7.0	12.0
pool (%)	0.0	0.0	100.0
distance to PHX (miles)	4.4	13.2	16.6
age of property	1.2	26.2	60.1
tract mean income ($)	34461.0	59886.0	110899.0
tract % white	61.0	83.1	94.8
tract % owners	33.6	65.2	89.9

Note: The table summarizes the 24,010 properties used in our main specification reported in (5) of Table 1. Panel A shows the 5th, 50th, and 95th percentiles of house and neighborhood characteristics among properties that experienced discernible changes in aircraft noise; i.e. properties located in shaded areas of Figure 2. In total, 2,742 properties experienced increased noise and 1,602 properties experienced decreased noise. Panel B shows the same percentiles for 19,666 "control" properties that did not experience discernible changes in noise; i.e. properties located in unshaded areas in Figure 2. Price and sale year percentiles are reported for the subset of transactions that occurred prior to NextGen. We suppress the following categorical house characteristics for brevity: heating system type, cooling system type, building materials for the walls and roof, garage type, patio type, and whether the property has multiple stories.

C Additional Results

Capitalization effects for noise bins. Our main specification restricts noise to be capitalized as a constant percentage change in property value per decibel. We relax this assumption by replacing our continuous measure of noise with indicators for five-decibel bins. To compare the results shown in column (1) of Table C.1 with our main specification, we measure the average percentage change at each bin midpoint. This implies point estimates and 95% confidence intervals of 1.4% [0.7%, 2.0%] per dB for the 55-60 dB range, 1.0% [0.2%, 1.7%] for the 60-65 dB range, and 2.7% [1.7%, 3.8%] above 65 dB. While these results suggest a larger capitalization rate over 65 dB, our data only contain 167 such properties (compared to $7,349$ properties with noise between 55 and 65 dB). Therefore, we conclude that the capitalization effect is approximately constant over the range of noise that is most relevant for measuring the causal effects of aircraft noise on property values in Phoenix.

Alternative normalization for low-level noise. Finally, we test the sensitivity of our estimates to the assumption that changes in aircraft noise below 55 dB are imperceptible. We repeat the bin estimator after lowering the threshold to 50 dB, consistent with ambient noise in quiet exurban areas (US Environmental Protection Agency, 1974; US Department of Transportation, 2018). The resulting capitalization effect per dB for the 50-to-55 dB bin shown in Column (2) of Table C.1 is less than half the size of our main estimate in Table 1 column (5) and indistinguishable from zero at the 10% level. We conclude that there is no compelling evidence that property values capitalize aircraft noise below the 55 dB threshold that the EPA defined as an adequate margin of safety for avoiding annoyance and interference with outdoor activities.

Table C.1: Alternate Specification: Noise Bins

	(1)	(2)
50 – 55 db	0.0000	-0.0128
	(.)	(0.0082)
55 – 60 db	-0.0346***	-0.0460***
	(0.0083)	(0.0109)
60 – 65 db	-0.0727***	-0.0851***
	(0.0281)	(0.0291)
Over 65 db	-0.3424***	-0.3551***
	(0.0685)	(0.0688)
R^2	0.942	0.942
# transactions	55,133	55,133
# properties	24,010	24,010

Note: The table reports coefficients from regressing log transaction prices on indicators for decibel ranges. In column (1) the reference range for aircraft noise is less than 55 decibels. In column (2) the reference range is less than 50 decibels. Both specifications are otherwise identical to our main specification in Table 1 Column (5). Specifically, both specification are estimated using repeat sales only and include property fixed effects and year-by-month fixed effects. Standard errors are clustered by noise grid cell by period. There are two periods: before and after flight paths changed. Asterisks denote statistical significance at * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.