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Buyer information and the hedonic: The impact of a seller disclosure on the implicit price for airport noise

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Abstract

Revealed preference methods like the hedonic model generally assume economic agents have access to publicly available information and use it effectively. In the housing market, the recent proliferation of seller disclosure laws suggests that policymakers perceive buyers to be less than "fully informed," presumably since they face higher information acquisition costs than sellers. The introduction of an airport noise disclosure in the residential housing market surrounding the Raleigh–Durham International Airport is used as a quasi-random experiment to analyze the impact of this type of information asymmetry between buyers and sellers on housing prices. The results from a regression analysis that controls for potential spatial and temporal confounders, suggest that the airport noise disclosure reduced the value of houses most heavily impacted by airport noise by 2.9 percent. This represents approximately a 37 percentage point increase in the implicit price of airport noise. The results provide evidence that publicly available information, such as that available for airport noise, may not be adequately considered by all buyers. They also suggest that the information environment should be carefully considered when using housing data and the hedonic model to value urban amenities and disamenities.

JEL classification: R21; R52; Q51; Q53

Keywords: Hedonic; Asymmetric information; Noise; Amenities

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1. Introduction

The hedonic model is a revealed preference approach to valuing the attributes of differentiated products that are not explicitly traded in their own markets. Rosen [15] is widely credited with developing the theoretical foundation for the interpretation of coefficients in properly specified hedonic price models. He showed that under ideal conditions including full information, the hedonic model suggests that an equilibrium price locus "reveals" the marginal values for small changes in each attribute that distinguishes a heterogeneous good. Applied to the housing market, the model has been widely used in urban economics to study such topics as the value of air quality (i.e. Nelson [12] and Chay and Greenstone [4]), crime (i.e. Thaler [17] and Bowes and Ihlanfeldt [2]), and school quality (i.e. Black [1] and Gibbons and Machin [7]).[1] However, if the full information assumption of the hedonic model is not satisfied, estimated implicit prices may not fully reflect the marginal values of households.

There has been a recent increase in government-mandated "seller" disclosure laws for differentiated products suggesting that buyers may not be fully informed as assumed by the hedonic model. The housing market for example, is currently being reshaped by disclosure laws. It is being transformed from a market where "caveat emptor" (buyer beware) ruled supreme to one where sellers are now required to provide various disclosures. Today most states have enacted some form of "seller disclosure" laws, apparently to reduce information asymmetries between buyers and sellers.[2] These laws not only require sellers to supply their "private" information about the quality of the house, they sometimes also re-provide information that was already "publicly available." Re-providing information that is already publicly available is in direct conflict with the hedonic model's assumption that buyers are fully informed. There has not been empirical work in the economic literature on the impact of re-providing public information to buyers in the housing market.

The seller disclosure laws in the housing market provide an opportunity to better understand the impact that asymmetric information acquisition between buyers and sellers may have on housing prices. They also provide the opportunity to understand how economic values derived from the hedonic method and the housing market may be affected when buyers are less than fully informed. In this study an airport noise disclosure serves as an information shock that can be used as a quasi-random experiment to test the impact of buyers' increased awareness and information about airport noise, on housing prices.

Although airports can provide many benefits such as increased service-related employment, increased tax revenues and reductions in transportation costs for businesses and the general public, airports can also impose costs such as noise pollution on those living in close proximity to the airport.[3] There have been many studies that have attempted to measure the external cost of airport noise by using the hedonic method and information on housing prices near airports (see Nelson [13] and McMillen [10] for summaries of previous work). As a result of these studies there is little controversy that airport noise does reduce housing prices in high noise areas near airports. However, why there are marked differences in estimated impacts in this literature for areas with similar noise levels has been questioned. This study highlights one possible expla-

[1] See Sheppard [16] and Palmquist [14] for extensive reviews on the hedonic method as applied to urban and environmental economics.

[2] See Lefcoe [9] for a discussion of real estate mandatory disclosure laws and their history.

[3] See Brueckner [3] for a discussion of some of the benefits and see [18,19] for information on why noise pollution is a leading environmental concern at major airports.

nation for the heterogeneity in these estimates of the impact of airport noise on housing prices that has not been explicitly considered in the previous work. The explanation is that homebuyers may not be fully informed about the extent of airport noise, causing a biasing effect on estimates.

Over the past twenty five years efforts have been made to limit the number of households exposed to significant noise levels of 65 decibels (dB) or more. However, airports receive numerous complaints from new residents, indicating that they were unaware of the presence or extent of the airport noise before purchasing their homes.[4] This suggests that although airport noise is considered public information, there are buyers that may not pay attention or gather sufficient information about this attribute before buying a house. This is especially true for airports that periodically change their flight paths or where distance to the airport from a given house is deceiving. The Raleigh–Durham International Airport (RDU) in North Carolina is an example of such an airport.

RDU became one of the first airports to successfully introduce a real estate disclosure requirement for airport noise. Furthermore, homeowners were unaware of the fact that they would be required to provide the disclosure until the law went into effect. This enhances the credibility of treating the disclosure as an exogenous disruption to the information environment to be used in an identification strategy. A key feature of North Carolina's Seller Disclosure law allowed RDU to enforce the airport noise disclosures in the local real estate market. In fact, RDU has a "noise officer" responsible for checking on homeowners and real estate agents for disclosure compliance and to answer questions from homebuyers. RDU apparently expected that the benefits (such as decreased liability to compensate nearby homeowners for airport noise) of implementing and enforcing the disclosure program, outweighed costs.

The circumstances associated with the RDU disclosure provides an opportunity to analyze how reasonable the full information assumption is in the hedonic model. Using data on housing sales occurring near the RDU airport that bracket the timing of the disclosure, it is possible to compare implicit prices for airport noise before and after this information shock. The results from a regression analysis that controls for potential spatial and temporal confounders suggest that the disclosure reduces the selling price of homes in high noise areas by approximately 2.9 percent. This reduction is in addition to the approximate 7.8 percent impact that would be attributed to airport noise in these areas prior to the disclosure. Thus these findings suggest that a hedonic price regression using the housing sales the year before disclosures began taking place would substantially underestimate the implicit price of airport noise.

One interpretation of these results is that a significant fraction of buyers in the housing market near RDU were unaware or uninformed about the extent of the airport noise prior to the disclosure. This is despite the fact that airport noise is thought to be a readily perceptible location specific disamenity. Information about differences in noise is publicly available. Therefore the structure of the conventional hedonic would imply noise should be capitalized in housing prices *prior to* the disclosure law. The robust estimate for the differential effect of the new disclosure policy is therefore difficult to reconcile with the assumption of full information.

Overall, the results emphasize the importance of understanding the information environment when using hedonic models. For the case of airport noise, lack of information on the part of buyers appears to bias the estimate of marginal values for airport noise towards zero. Thus dif-

[4] This anecdotal evidence was acquired by searching newspapers in metropolitan areas, by reading logged complaints on airport websites, and talking with real estate agents.

ferences in how informed buyers are of airport noise in different housing markets may be one reason for the heterogeneity in the estimates of the implicit price for airport noise in the literature. Furthermore, many other situations where economists use the hedonic method and housing data may also be susceptible to a similar type of bias.

The remainder of this study will proceed as follows. Section 2 provides background on RDU's airport noise disclosure program. Section 3 describes the data used in the analysis. Section 4 outlines the identification strategy used to isolate the impact of the noise disclosure on housing prices. Section 5 describes the results of a series of hedonic price regressions. Section 6 concludes the study.

2. The airport noise disclosure program

A set of unique events occurred at the Raleigh–Durham International Airport (RDU) that allows a test of whether or not buyers were aware and fully informed about airport noise. In June of 1987 American Airlines opened a hub at RDU, causing the number of flights at the airport to approximately double. This change increased the amount of aircraft related noise experienced by nearby homeowners. After this expansion, 125 homeowners sued the Raleigh–Durham Airport Authority (the governing body for the airport which will be referred to as RDU) complaining that the increased noise had reduced their property values. In 1992 RDU settled the lawsuit by agreeing to pay 1.8 million dollars to the 125 homeowners. Most homeowners were compensated in the range of $11,000 to $23,000 depending on the amount of noise experienced at the location of the house and the value of the house. The average compensation received by the homeowners participating in the lawsuit was $14,400.[5]

The lawsuit prompted RDU to consider a number of ways to reduce their future liability. For example, in 1994 RDU made recommendations to the towns affected by airport noise on how to pass ordinances that among other things would require homeowners to notify buyers of potential aircraft noise problems. However, the ordinances were strongly opposed by developers and homeowners, who did not want to provide the noise disclosure and risk further reducing their property values. Without constituent support, towns were unable to pass the ordinances recommended by RDU.

In 1995 North Carolina General Statute 47E known as the "Residential Property Disclosure Act," was passed requiring owners of residential real estate to provide prospective buyers with a property disclosure statement after January 1, 1996. Although there was nothing about airport noise on the disclosure statement, part of the statute required that any notification from a government agency affecting the property must also be furnished to prospective buyers. RDU, which is recognized as a government agency in the state of North Carolina, used this opportunity to require homeowners to provide a separate airport noise disclosure. RDU developed a notification letter and map that was sent out in March of 1997 to all homeowners within specified noise contours (see Fig. 1 for copies of the letter and map).[6] Additionally the information was sent to real estate agents in the area and a "noise officer" from RDU made spot checks to ensure that both sellers and their agents were using the disclosure letter and map for each housing transaction that

[5] These dollar amounts are in 1992 dollars and based on reports in the primary local paper "The News and Observer."

[6] The letter and map have been mailed two times since the initial mailing—once in April 2000, and again in May 2004. Furthermore, the letter and map is available on RDU's website and many real estate agents in the area provide a link to these digital copies on their websites.

AIRCRAFT NOISE NOTIFICATION

Dear Property Owner:

You are listed by the Wake County Tax Office as the owner of a parcel of land located within the general area surrounding Raleigh-Durham International Airport (RDU) that is exposed to average aircraft noise levels which exceed typical ground-based, or background, noise. The map displays that area and shows contours of equal average aircraft noise exposure associated with current flight operations at the airport and those projected through approximately the year 2010. Sites closer to the airport are exposed to higher average noise levels than those farther away.

The purpose of this notice is to advise you that exposure to aircraft noise may affect the usability of some land for certain types of noise sensitive uses, including residential use. Persons who are sensitive to aircraft noise should satisfy themselves before buying the property that exposure to such noise will not materially affect their ability to use and enjoy land whose purchase they may be considering.

The Raleigh-Durham Airport Authority has and, upon request, will provide information which may be helpful to property owners and prospective purchasers in assessing the likely effect of aircraft noise on the use of land they own or are considering purchasing.

You also are advised that the "Residential Property Disclosure Act" (N.C.G.S. Chapter 47E) was enacted by the North Carolina General Assembly and became effective January 1, 1996. That law requires the owners of residential real property to disclose to prospective purchasers the existence of certain conditions associated with the property no later than the time an offer to purchase, exchange or option the property is made, or an option to purchase the property pursuant to a lease with an option to purchase is exercised.

Among the conditions that must be disclosed to and acknowledged by the prospective purchaser are any notice from any governmental agency affecting the property. The Airport Authority is a governmental agency. THIS NOTICE SERVES AS YOUR NOTICE OF POTENTIAL AIRCRAFT NOISE IMPACT UPON YOUR PROPERTY AND SHOULD BE DISCLOSED TO ALL PROSPECTIVE PURCHASERS WHO MAY BE CONSIDERING USE OF THE PROPERTY FOR A RESIDENTIAL PURPOSE.

For additional information or if you have questions or need assistance, please call the RDU Noise Officer at 919-840-2100 between 9:00 a.m. and 5:00 p.m. Monday-Friday or write to:

Noise Officer
Raleigh-Durham Airport Authority
P. O. Box 80001
RDU Airport, North Carolina 27623-0001

The Raleigh-Durham Airport Authority

Fig. 1. RDU notification letter and map.

occurred in the area. The airport noise disclosure developed by RDU appears to have occurred unexpectedly.[7]

[7] A search of the primary local paper "The News and Observer" shows no articles revealing that RDU had developed or was going to implement their noise disclosure program leading up to the mailing of the letters and maps.

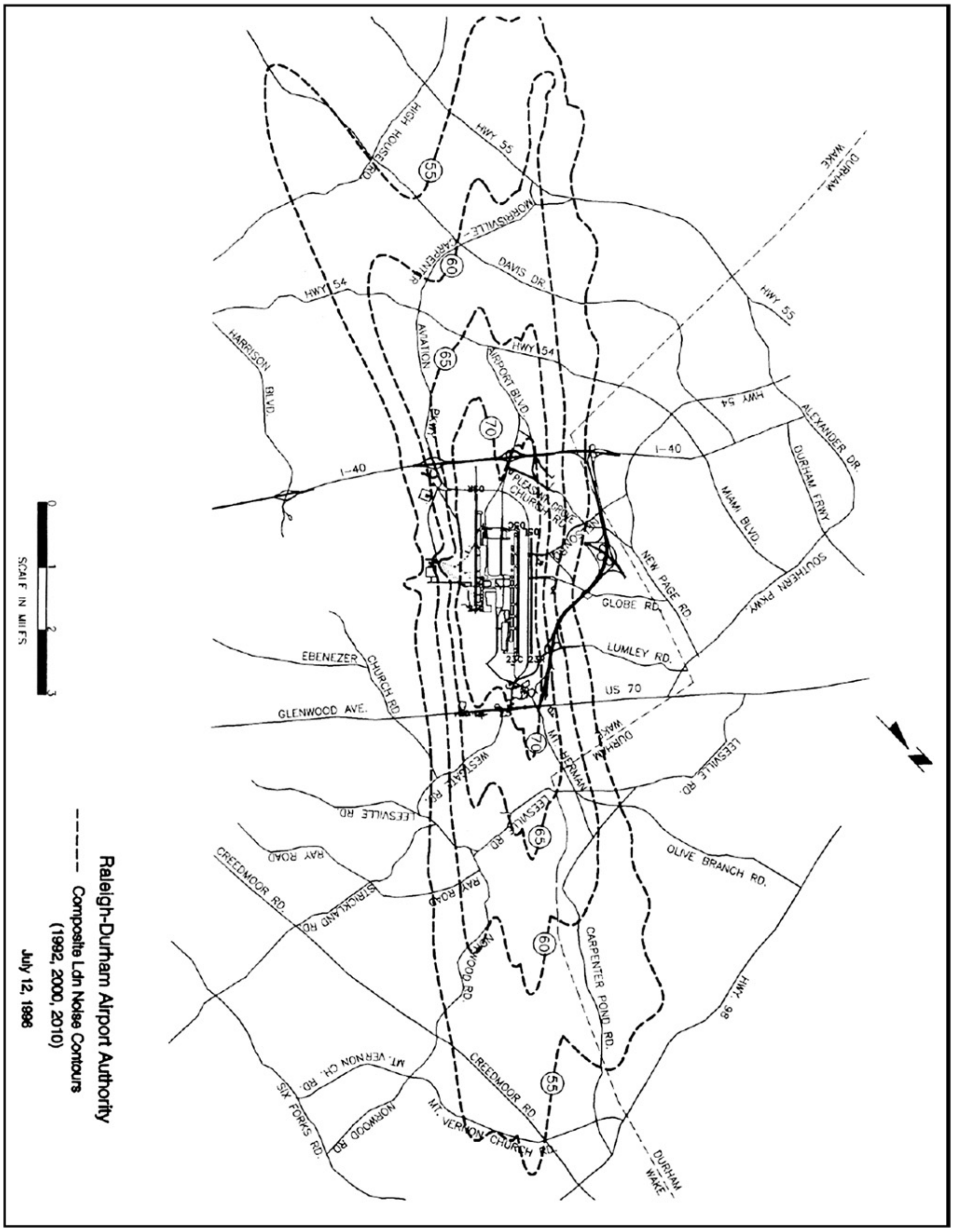

Fig. 1. (*continued*)

In the time since airport noise disclosure has been mandatory, RDU has supported plaintiffs in two Wake County Superior Court cases where sellers failed to present buyers with an airport noise disclosure. In these cases the buyers sued the sellers because they claimed they were unaware of the airport noise issue before buying their houses. This type of ignorance may have occurred for two reasons. First airport noise is not constant. It changes throughout the day and throughout the week. In fact, anecdotal evidence suggests that prior to the introduction of the noise disclosure real estate agents exploited this temporal variation in noise by showing homes near the airport during low noise time periods. Furthermore, the area surrounding the airport is wooded and it is difficult to see the location of the airport while visiting a property. Thus some buyers may remain uninformed even after having visited the house several times.

These court cases illustrate both the potential for buyers to be inattentive or uninformed about the airport noise attribute of housing. They also illustrate the firm stance that RDU has taken on its airport noise disclosure. Personal conversations with the RDU noise officer suggest that compliance has been exceptional since the airport noise disclosures have been required. Therefore the disclosure provides a quasi-random experiment to further understand if buyers can be characterized as "fully informed" about urban disamenities such as airport noise.

3. Data used in the analysis

There are several sources of data that are needed to estimate the impact of the airport noise disclosure on housing prices. The primary dataset used in this analysis consists of single-family housing transactions occurring between 1992 and 2000 in Wake County North Carolina.[8] Data on sale prices and property characteristics were compiled from information provided by the Wake County Revenue Department. Sales were screened to ensure that they were arms-length and to eliminate outlying observations. A GIS shapefile was acquired from the Wake County GIS department that georeferenced each of the house locations in the above dataset of housing transactions. Using this GIS shapefile a variety of other variables were linked spatially to the housing locations using ArcView GIS.

RDU provided a GIS shapefile for this analysis that spatially referenced noise contour zones of 55 Ldn or greater. These noise zones are those that required the noise disclosure after April 1, 1997.[9] These noise contour zones are a composite of present and future expectations about noise levels around the airport.[10] The housing dataset was then screened to include only those housing transactions that were in noise zones requiring disclosure, or housing transactions within a one mile buffer around this area of disclosure. The houses within this one mile buffer act as a natural control group. Figure 2 shows housing locations in relation to the airport noise zones and Table 1 provides descriptions and summary statistics for the variables used in the analysis.

Structural control variables include age of the house, number of bathrooms, acreage of the lot, heated area other than attic and basement, detached garage dummy, number of fireplaces, deck area, sewer availability dummy, hardwood floors dummy, screen porch area, brick walls dummy, attic heated area, basement heated area, garage area, pool dummy, full basement dummy, partial basement dummy, enclosed porch area and a set of dummies denoting an assessment of housing condition. Unlike housing data commonly used for hedonic analysis, variables such as garage and basement heated area have the square feet calculated rather than simply denoted by

[8] The airport is located on the western side of Wake County near the Durham County line. Most of the residential properties affected by noise from the airport are located in Wake County. However, there are a small number of properties located within Durham County that are potentially impacted by airport noise that are excluded from the analysis.

[9] Ldn stands for "level day night" which is a day–night weighted average noise level in decibels where nighttime noise is weighted more heavily than daytime noise because it is considered more obtrusive.

[10] The noise contour map states that the contours are based on "current flight operations at the airport and those projected through approximately the year 2010."

Table 1
Summary statistics

Variable	Description	Mean	Median	Standard deviation	Minimum	Maximum	Observations
lprice	Log of sale price of property	12.16	12.11	0.34	9.68	14.82	16,900
age	Age of house in years	3.54	1	5.80	0	97	16,900
baths	Number of bathrooms	2.85	2.50	0.65	1	7	16,900
acreage	Lot size in acres	0.41	0.27	0.60	0.06	37.53	16,900
regheatarea	Main heated living area in sq. ft.	2295.39	2243	646.83	620	5704	16,900
detgarage	Detached garage dummy	0.01	0	0.12	0	1	16,900
fireplaces	Number of fireplaces	0.98	1	0.21	0	4	16,900
deck	Deck area in sq. ft.	186.26	168	142.10	0	1545	16,900
sewer	Sewer availability dummy	0.902964	1	0.2960151	0	1	16,901
flordum1	Hardwood floors dummy	0.01	0	0.10	0	1	16,900
scrporch	Screened porch area in sq. ft.	16.91	0	58.03	0	1050	16,900
walldum1	Brick walls dummy	0.05	0	0.22	0	1	16,900
atticheat	Attic heated area in sq. ft.	56.83	0	163.32	0	1743.33	16,900
bsmtheat	Basement heated area in sq. ft.	24.44	0	163.29	0	2690	16,900
garage	Garage area in sq. ft.	432.82	462	184.79	0	1268	16,900
poolres	Pool dummy	0.01	0	0.08	0	1	16,900
bsmtdum1	Full basement dummy	0.04	0	0.20	0	1	16,900
bsmtdum2	Partial basement dummy	0.02	0	0.14	0	1	16,900
encporch	Enclosed porch area in sq. ft.	1.52	0	20.01	0	990	16,900
opnporch	Open porch area in sq. ft.	54.43	30	74.83	0	1161	16,900
condadum	House of "A" condition dummy	0.02	0	0.15	0	1	16,900
condcdum	House of "C" condition dummy	0.01	0	0.08	0	1	16,900
condddum	House of "D" condition dummy	0.00	0	0.03	0	1	16,900
perc_nonwhite_1990	percent non-white	9.94	7.97	5.32	0	69.64	16,900
medianvalue_int	Median house values	185,838.00	183,920	37,864.09	99,240	559,810	16,900
medttw_int	Median time to work	21.88	22	1.79	17	27	16,900
perc_under18_int	Percent population < 18	29.45	30.54	4.16	7.38	38.51	16,900
perc_owner_occ_int	Percent owner occupied housing	78.90	85.05	16.59	14.62	95.56	16,900
nearestpark	Distance to nearest park	3.62	3.53	1.47	1.08	8.37	16,900
nearestsc	Distance to nearest shopping center	6.49	6.13	1.88	2.92	13.95	16,900
taxrate	Property tax rate for area	0.38	0.54	0.24	0	0.60	16,900
yrdum93_apr	April 1993 to April 1994 dummy	0.12	0	0.32	0	1	16,900
yrdum94_apr	April 1994 to April 1995 dummy	0.12	0	0.32	0	1	16,900
yrdum95_apr	April 1995 to April 1996 dummy	0.12	0	0.33	0	1	16,900
yrdum96_apr	April 1996 to April 1997 dummy	0.13	0	0.33	0	1	16,900
yrdum97_apr	April 1997 to April 1998 dummy	0.13	0	0.34	0	1	16,900
yrdum98_apr	April 1998 to April 1999 dummy	0.14	0	0.35	0	1	16,900
yrdum99_apr	April 1999 to April 2000 dummy	0.09	0	0.29	0	1	16,900
yrdum00_apr	April 2000 to January 2001 dummy	0.05	0	0.23	0	1	16,900
airport_dist	Linear distance to Airport	6.21	6.46	1.62	1.66	9.65	16,900
new_sale	New property sale dummy	0.42	0	0.49	0	1	16,901
north	Northern Region dummy	0.33	0	0.47	0	1	16,901
interstate	Distance to interstate function	0.14	0	0.21	0	0.74	16,901
noise55_dum	In 55–65 dB zone dummy	0.47	0	0.50	0	1	16,900
noise65_dum	In 65–70 dB zone dummy	0.05	0	0.22	0	1	16,900
noise55_post	In 55–65 dB zone & sold with disclosure	0.19	0	0.39	0	1	16,900
noise65_post	In 65–70 dB zone & sold with disclosure	0.03	0	0.16	0	1	16,900

Table 2
Number of observations for key dummy variables

Variables	Number of observations		
	(1) (1992–2000)	(2) (1995–1998)	(3) (1996–1997)
noise65_dum	854	513	292
noise65_post	472	347	190
noise55_dum	7866	3790	1857
noise55_post	3174	2035	973
Total # of obs. in sample	16,900	8873	4369

a dummy variable. Thus this dataset provides the analyst with a very detailed set of structural control variables.

Neighborhood control variables derived from census block group level data include percent non-white, median house values, median time to work, percent of population under 18 years of age and percent owner occupied housing. In addition to these census variables, variables were created to measure the distance to the nearest park, the distance to the nearest shopping center, and the property tax rate for the area.

The estimation strategy, discussed in detail below, utilizes a fixed-effects model in time and space. Therefore yearly dummy variables were created for the years 1992–2000.[11] For example, yrdum93_apr in Table 1 is a dummy variable equal to 1 for all houses transacted from April 1, 1993 to April 1, 1994. Years are broken up from April to April to facilitate analyzing the impact of airport noise disclosures which began taking place on April 1, 1997.

Four spatial variables were created to represent the spatial relationship between each house and the airport. First, the variable airport_dist is the linear distance between each house and the main entrance to the airport terminals. The variable noise65_dum is a dummy variable equal to 1 if the house lies in the 65–70 Ldn noise contour, where disclosure was mandatory after April 1, 1997. The variable noise55_dum is a similar dummy variable which is equal to 1 if the house lies in the 55–65 Ldn noise contour, where disclosure was also mandatory after April 1, 1997. Finally, the last dummy variable is set equal to 1 if the house lies in the 1 mile buffer zone just outside the 55–65 Ldn noise contour, where there was no disclosure requirement after April 1, 1997.[12] Two additional dummy variables, noise55_post and noise65_post are created that are equal to 1 for houses that lie in the 55–65 Ldn and 65–70 Ldn zones respectively and were *transacted* after April 1, 1997. Table 2 provides the counts of housing transactions for noise55_dum, noise65_dum, noise55_post and noise65_post over different time horizons used in the analysis.

To appreciate the consequences of living in a 55–65 Ldn noise contour zone or a 65–70 Ldn noise contour zone, it is useful to consider how human perception of noise disturbance is related to the decibel scale which is used to create the measures of Ldn.[13] Humans perceive noise on a log scale rather than a linear scale. Noise is perceived to be twice as loud for every increase of 10 dB. Typical background noise levels in urban areas have been estimated to be between 50 and 60 dB during the day and 40 dB at night. For example, light traffic a hundred feet away would

[11] The 1992 dummy is the omitted variable in the estimation.

[12] The dummy variable representing houses in the 1 mile buffer area is omitted in the estimation.

[13] As footnoted earlier, Ldn stands for "level day night" which is a day-night weighted average noise level in decibels where nighttime noise is weighted more heavily than daytime noise because it is considered more obtrusive.

likely register at over 50 dB's. Houses in the 65–70 Ldn zone are likely to experience aircraft noise that is perceived as roughly twice as loud as the noise experienced on average by those living in the 55–65 Ldn contour and roughly 3–4 times as loud as houses in the 1 mile buffer. Federal Aviation Administration (FAA) regulations only pertain to housing in areas of 65 Ldn's or above.

4. Identification strategy for the hedonic model

The temporal source for variation in information about airport noise arises from disclosures that began at the end of March 1997. Spatial variation on noise impact zones stems from the noise contours provided by RDU. A simple estimation approach using the compiled housing dataset and these sources of temporal and spatial variation using a fixed-effects approach and a semi-log form, is as follows,[14]

$$\begin{aligned} \text{lprice} = {} & \beta + \alpha\,\text{Structural} + \phi\,\text{Neighborhood} \\ & + \delta\,\text{yrdum93\_apr} \ldots \text{yrdum00\_apr} \\ & + \theta\,\text{noise55\_dum} + \gamma\,\text{noise65\_dum} \\ & + \lambda\,\text{noise55\_post} + \psi\,\text{noise65\_post} + \varepsilon \end{aligned} \tag{1}$$

where the variables are defined as in Table 1, ε is an error term and β, θ, γ, λ, and ψ are parameters to be estimated and α, ϕ, and δ represent vectors of parameters to be estimated. In experimental terminology houses in the 55–65 and 65–70 Ldn contours have been "treated" by the airport noise disclosure while the houses in the one mile buffer area are "untreated" and act as a control. Using the estimating equation above, the coefficients on noise55_post and noise65_post would provide estimates of the impact of the airport noise disclosure on housing prices in these disclosure zones relative to houses in the one mile buffer control area.

4.1. Controlling for potential confounding influences

As discussed in Meyer [11], there are a number of potential confounders when applying the quasi-random experiment methodology. Foremost among these is omitted variables bias, which in this context could occur from other factors that change over time or over space and lead to a mis-measurement of the disclosure effect. One potential spatial confounder that is acknowledged by previous studies of the impact of airport noise on housing prices is that proximity to an airport can also be a desirable attribute for households because it provides convenient access to airport services. If airport noise were evenly distributed in space around an airport it would be very difficult to identify the positive and negative effects due to living near an airport. However, airport noise is typically greatest extending out from the ends of the runways with much less noise extending outwards from the sides of the runways. Thus by including a distance measure to the main entrance of the airport, it is possible to account for this effect and be reasonably confident the variable being used is uncorrelated with the noise measures.

[14] Work by Cropper et al. [5] suggests that the semi-log form is often desirable. They used an assignment model to construct the "true" hedonic equilibrium to analyze the properties of hedonic price functions. Their primary finding was that when all attributes are observed by the researcher, the quadratic Box–Cox performed best. However, when there were omitted variables or proxy variables were used, the simpler functional forms such as the linear and semi-log forms estimated the marginal attribute prices most accurately.

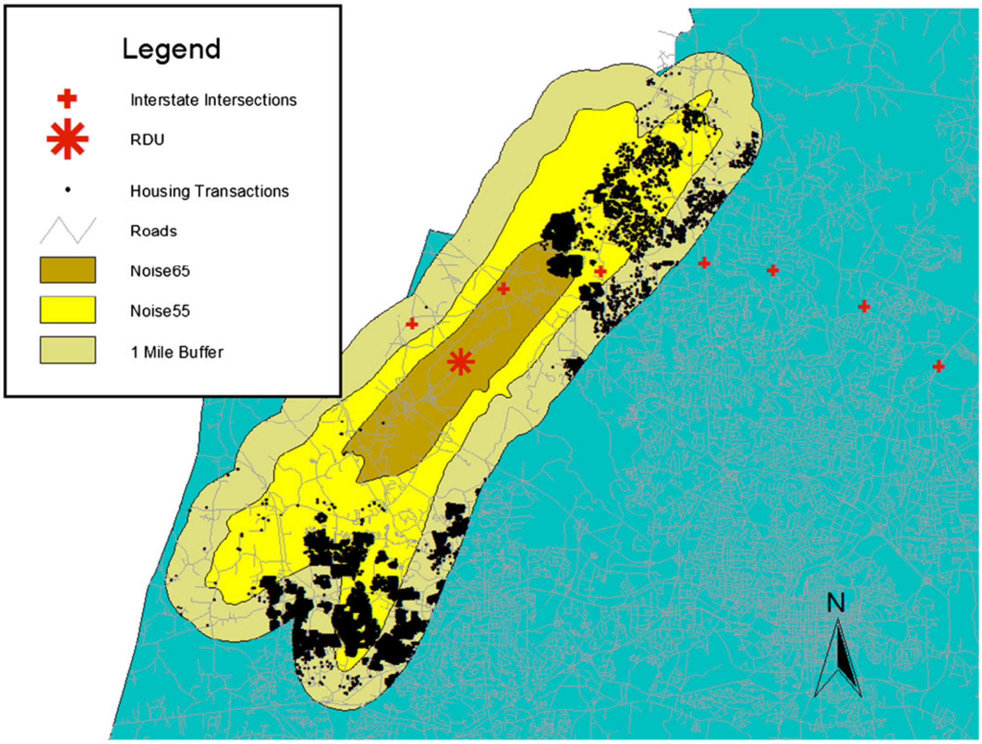

Fig. 2. Housing transactions and disclosure zones.

Another potential spatial confounder can be seen in Fig. 2. Houses in the vicinity of the airport are grouped primarily in a northern set and a southern set. If the block group level controls, tax rate information and other spatial variables included in the regression are not adequately controlling for differences between the northern and southern groups, then the noise contours may be picking up some of these differences. To address this possibility, a dummy variable was created for the northern grouping and included in the analysis.

There were a number of new homes built in the vicinity of the airport during the 1992–2000 period included in the dataset. If there is something unique about this new housing stock built over this time period in the area near the airport relative to the existing housing stock, this could potentially bias the results. To avoid this bias, a dummy variable was created for houses that sold in the same year that they were built. Although it is possible that houses sold more than once in the year after they were built, this variable should act as a reasonably good proxy for newly built homes.[15]

An interstate (I-540) highway that passes through the northern sample of houses has been under construction since 1992, which is still ongoing. If the benefits of this interstate are correlated

[15] This variable is also important because the NC property disclosure law does not apply to brand new housing. However, while RDU airport authority cannot enforce compliance they have asked all developers to also provide the disclosure and make checks on whether or not the disclosure occurs for new housing. Discussions with the noise officer suggest that compliance for new houses is nearly as high as for houses that resale. Nonetheless the new sale dummy is important for capturing any differences in propensity to disclose.

with airport noise, this could potentially bias empirical estimates as well. To overcome this bias, a GIS street file was acquired that shows the entrances and exits (intersections) to this new interstate. A GIS point file was created from the street file for each of these intersections (see Fig. 2). Linear distances from each house to the nearest intersection were then calculated. Because the benefits associated with the interstate likely dissipate the further a home is from an intersection (for example the houses in the southern sample are likely to derive almost no benefit due to their house location) the following function was used to relate houses to benefits from the interstate:

$$\text{interstate} = \max\left[1 - (d/d_{\max})^{1/2}, 0\right], \tag{2}$$

where d is distance in miles and $d_{\max}$ is a benefit cutoff point set to 4 miles for this application. This function creates a convex index between zero and one.[16]

Another concern for this analysis is that airport noise or expectations about airport noise could have changed dramatically during the study period, thereby confounding the ability to detect the impact of the noise disclosure. For this concern to be valid, noise or expectations of noise would have needed to increase sharply at the same time as when the noise disclosure began taking place. To explore this possibility, statistics were gathered on the number of travelers passing through RDU by year, which are presented in Table 3. The number of travelers using RDU increased considerably in the late 1980's, coinciding with American Airlines designation of RDU as one of its hubs. During the early 1990's the traffic passing through RDU was relatively constant. However, a dip in traffic can be seen between 1994 and 1995, coinciding with American Airlines closing its hub during this time period. From 1995–2006 it can be seen that traffic slowly increases and then plateaus at levels coinciding with the early 1990's. These statistics suggest that expectations of noise are unlikely to bias estimates of the impact of the disclosure. This is because any expectations based on prior airport traffic/noise, or expectations that anticipated the future level of airport traffic/noise were likely to have been similar. Furthermore, because quieter commercial jet engines were gradually being phased in over this same time period, actual airport noise levels were slowly declining. Thus any bias from expectations or actual noise levels will likely dampen estimates of the impact of the noise disclosure rather than exaggerate.[17]

Although considerable effort was devoted to discover spatial and temporal confounders, it is difficult to be certain that there were no other potential temporal-spatial interactions during the 1992–2000 time period. Thus some form of sensitivity analysis for the time period chosen in the empirical analysis is desirable. This strategy reduces the likelihood that omitted spatial factors correlated with the timing of the airport noise disclosure are responsible for the findings. One approach would be to restrict the sample used in the analysis to those houses whose transaction dates were temporally proximate to the April 1, 1997 date when disclosures began. This restriction should be useful in determining whether the smaller sample affects the estimates of the impact of the noise disclosure.

When Eq. (1) is updated to include the variables used to control for spatial influences and to restrict the time interval to the year before and after disclosures began taking place, the result is Eq. (3),

[16] Of course houses extremely close to an intersection may be negatively affected by traffic noise; however this is a very small percentage of houses and so should not bias the results.

[17] According to RDU's website, this phasing out of noisier "stage 2" engines to the quieter "stage 3" engines appears to have occurred throughout the mid to late 1990's and was completed in 2004.

Table 3
Annual passengers traveling through RDU

Year	Enplaned	Deplaned	Total
1985	1,381,798	1,389,211	2,771,009
1986	1,555,362	1,544,640	3,100,002
1987	2,428,101	2,425,972	4,854,073
1988	3,696,712	3,655,295	7,352,007
1989	4,318,325	4,276,346	8,594,671
1990	4,650,872	4,614,793	9,265,665
1991	4,698,543	4,683,043	9,381,586
1992	4,977,071	4,948,293	9,925,364
1993	4,862,285	4,833,601	9,695,886
1994	4,498,837	4,500,654	8,999,491
1995	2,962,701	2,974,434	5,937,135
1996	3,206,136	3,211,735	6,417,871
1997	3,360,478	3,364,396	6,724,874
1998	3,615,439	3,613,214	7,228,653
1999	4,471,065	4,470,710	8,941,775
2000	5,210,297	5,228,288	10,438,585
2001	4,806,513	4,777,474	9,584,087
2002	4,252,453	4,221,044	8,473,497
2003	3,968,186	3,944,361	7,912,547
2004	4,352,702	4,352,702	8,637,606
2005	4,654,585	4,649,319	9,303,904
2006	4,722,148	4,699,964	9,422,112

Notes: Statistics were acquired from the RDU website.

$$\begin{aligned}\text{lprice} = {} & \beta + \alpha\,\text{Structural} + \phi\,\text{Neighborhood} \\ & + \delta\,\text{yrdum97\_apr} \\ & + \theta\,\text{noise55\_dum} + \gamma\,\text{noise65\_dum} \\ & + \lambda\,\text{noise55\_post} + \psi\,\text{noise65\_post} \\ & + \vartheta\,\text{airport\_dist} + \rho\,\text{interstate} \\ & + \omega\,\text{new\_sale} + \pi\,\text{north} + \varepsilon \qquad (3)\end{aligned}$$

where airport_dist is the linear distance from each house to the airport entrance, interstate is the distance measure described by Eq. (2), new_sale is a dummy variable denoting houses that were transacted for the first time and north is a dummy for the houses north of the airport. In this specification the 1997 year dummy is included and the 1996 year dummy is omitted because only two years of housing data from April 1996 to April 1998 are used. Equation (3) is the primary regression equation used to derive the results reported in Section 5.

5. Results

5.1. Primary results

Columns (1)–(3) in Table 4 contain estimation results from the semi-log least squares specification corresponding with Eq. (3). Column (1) uses the full temporal sample of housing transactions between 1992 and 2000. Column (2) temporally restricts the sample to the years

Table 4
Airport noise regression results

Variable	Dep. Var. = lprice		
	OLS (1992–2000) (1)	OLS (1995–1998) (2)	OLS (1996–1997) (3)
new_sale	−0.001	0.008	−0.002
	[0.002]	[0.003]**	[0.004]
north	0.004	−0.010	−0.015
	[0.008]	[0.011]	[0.015]
interstate	−0.151	−0.140	−0.095
	[0.015]**	[0.021]**	[0.028]**
airport_dist	−0.011	−0.014	−0.014
	[0.001]**	[0.002]**	[0.003]**
noise55_dum	−0.023	−0.029	−0.026
	[0.003]**	[0.004]**	[0.006]**
noise65_dum	−0.051	−0.063	−0.078
	[0.007]**	[0.010]**	[0.012]**
noise55_post	0.012	0.013	−0.001
	[0.004]**	[0.005]**	[0.007]
noise65_post	**−0.031**	**−0.030**	**−0.029**
	[0.008]**	[0.012]**	[0.014]**
Constant	11.110	11.348	11.339
	[0.019]**	[0.030]**	[0.042]**
lag model parameter			
Structural & Neigh. Controls	X	X	X
Year fixed effects	X	X	X
Observations	16,900	8873	4369
R-squared	0.89	0.88	0.89

Notes: Standard errors in brackets.
* Significant at 10%.
** Significant at 5%.

1995 through 1998. Column (3) further restricts the sample to the years 1996 and 1997. Estimates of the parameters for the structural and neighborhood characteristics and temporal fixed effects have been omitted from Table 4, but were consistent with a priori expectations and other hedonic studies using similar variables. These results are reported in Table 5.[18]

As can be seen in column (1) of Table 4, the estimates for the dummy variables new_sale and north suggest that any differences between new and existing houses and houses in the north and the south groupings are being controlled with the structural and neighborhood characteristics included in the regressions. The coefficient on airport_dist is negative and highly significant in columns (1)–(3) suggesting that homeowners value access to the airport. The coefficient on interstate is also negative and highly significant, indicating access to the newly built interstate is

[18] The estimated parameters for the yearly fixed effects are all of the expected sign and magnitude. Prices are increasing for housing in this area of Wake County over the time period. Also note that although the yearly fixed effects in the columns labeled 1995–1998 and 1996–1997 are reported in Table 5, they are not directly comparable because the omitted dummy is not the same.

Table 5
Additional regression results

Variable	Dep. Var. = lprice		
	OLS (1992–2000) (1)	OLS (1995–1998) (2)	OLS (1996–1997) (3)
yrdum93_apr	0.054		
	[0.004]**		
yrdum94_apr	0.138		
	[0.004]**		
yrdum95_apr	0.181		
	[0.004]**		
yrdum96_apr	0.199	0.018	
	[0.004]**	[0.004]**	
yrdum97_apr	0.231	0.050	0.036
	[0.005]**	[0.005]**	[0.005]**
yrdum98_apr	0.258	0.077	
	[0.005]**	[0.005]**	
yrdum99_apr	0.290		
	[0.005]**		
yrdum00_apr	0.327		
	[0.006]**		
age	−0.006	−0.006	−0.008
	[0.000]**	[0.000]**	[0.000]**
baths	0.028	0.025	0.03
	[0.002]**	[0.003]**	[0.003]**
acreage	0.075	0.071	0.08
	[0.002]**	[0.003]**	[0.004]**
regheatarea	2.75E−04	2.65E−04	2.65E−04
	[0.000]**	[0.000]**	[0.000]**
detgarage	0.08	0.066	0.091
	[0.008]**	[0.011]**	[0.015]**
fireplaces	0.005	0.006	0.012
	[0.004]	[0.006]	[0.008]
deck	1.81E−04	1.92E−04	1.95E−04
	[0.000]**	[0.000]**	[0.000]**
sewer	−0.024	−0.033	−0.045
	[0.004]**	[0.006]**	[0.008]**
flordum1	−0.028	−0.04	−0.006
	[0.010]**	[0.015]**	[0.019]
scrporch	2.82E−04	3.39E−04	3.16E−04
	[0.000]**	[0.000]**	[0.000]**
walldum1	0.099	0.122	0.135
	[0.004]**	[0.006]**	[0.008]**
atticheat	1.89E−04	1.84E−04	1.91E−04
bsmtheat	8.44E−05	7.16E−05	6.29E−05
	[0.000]**	[0.000]**	[0.000]**
garage	3.15E−04	3.19E−04	2.88E−04
	[0.000]**	[0.000]**	[0.000]**
poolres	0.008	0.004	−0.014
	[0.011]	[0.015]	[0.018]
bsmtdum1	0.09	0.09	0.101

Table 5 (*continued*)

Variable	Dep. Var. = lprice		
	OLS (1992–2000) (1)	OLS (1995–1998) (2)	OLS (1996–1997) (3)
	[0.005]**	[0.007]**	[0.010]**
bsmtdum2	0.073	0.089	0.095
	[0.007]**	[0.010]**	[0.014]**
encporch	4.71E−05	1.93E−05	−1.73E−04
	[0.000]	[0.000]	[0.000]
opnporch	1.31E−04	1.63E−04	9.33E−05
	[0.000]**	[0.000]**	[0.000]**
condadum	0.065	0.057	0.055
	[0.007]**	[0.009]**	[0.013]**
condcdum	−0.066	−0.064	−0.14
	[0.012]**	[0.019]**	[0.028]**
condddum	−0.101	−0.139	−0.151
	[0.030]**	[0.045]**	[0.076]**
perc_nonwhite_1990	−4.91E−04	−0.001	−0.001
	[0.000]**	[0.000]**	[0.000]*
medianvalue_int	−5.98E−03	7.82E−07	8.01E−07
	[0.000]**	[0.000]**	[0.000]**
medttw_int	−0.006	−0.007	−0.006
	[0.001]**	[0.001]**	[0.001]**
perc_under18_int	0.002	0.002	0.002
	[0.000]**	[0.001]**	[0.001]**
perc_owner_occ_int	−0.001	−0.001	−0.001
	[0.000]**	[0.000]**	[0.000]**
nearestpark	0.006	0.004	0.005
	[0.001]**	[0.002]**	[0.002]**
nearestsc	0.003	0.006	0.005
	[0.001]**	[0.001]**	[0.002]**
taxrate	0.066	0.056	0.073
	[0.008]**	[0.011]**	[0.014]**
Observations	16,856	8846	4353
R-squared/pseudo	0.89	0.88	0.89

Notes: Standard errors in brackets.
* Significant at 10%.
** Significant at 5%.

valued by homeowners. The coefficient on noise55_dum suggests that houses in the 55–65 Ldn aircraft noise zone sold for approximately 2.3% less than comparable homes in the 1 mile buffer zone.[19] The coefficient on noise65_dum suggests a more substantial price impact of approxi-

[19] As noted by Halvorsen and Palmquist [8], coefficients on dummy variables in a semi-log regression cannot be interpreted as 1/100th of the percentage effect of that variable on the variable being explained like the coefficients on continuous variables. However the closer a dummy variable coefficient is to zero, the reported coefficients multiplied by 100 are likely to be more accurate estimates of the percentage effect of that variable on the variable being explained than if the coefficient is large (i.e. the more accurate approximation of a coefficient of −0.3 is −2.96%). Percentages reported in the text of this paper are the more accurate Halvorsen and Palmquist adapted estimates rounded to the second decimal place.

mately 5.1% on housing in the 65–70 Ldn noise contour. These estimates are consistent with the existing estimates of the impact of airport noise in the literature.[20]

The variables of primary interest in Table 4 are those labeled noise55_post and noise65_post denoting those housing transactions in the 55–65 and 65–70 Ldn zones respectively that took place after April 1, 1997. As discussed in Section 2, if the coefficients on noise55_post and especially noise65_post are insensitive to the temporal bounding restriction around when disclosures began taking place, then this strengthens the credibility of the identification strategy. The coefficient on noise55_post is small, positive, and statistically significant in columns (1) and (2), but in column (3) where housing transactions have been tightly bounded around the disclosure date, it becomes negative and is not statistically significant. The coefficient on noise65_post, however, is consistently negative and statistically significant for all three temporal sample types. Therefore, assuming that the tightly bounded third regression is most likely to correctly identify the relationship between airport disclosure and housing prices, the coefficients from this regression suggest that the airport noise disclosure that began taking place on April 1, 1997 further reduced property values of houses in the 65–70 Ldn zone by approximately 2.9%.

5.2. Discussion of results

These results indicate that the airport noise disclosure had an impact on housing prices near the RDU airport. One interpretation of this result is that buyers were less than fully informed about airport noise in this housing market prior to the disclosure. This lack of information appears to matter for the estimated marginal value of airport noise. In the most tightly controlled regression, that uses a limited temporal sample of houses that bracket the RDU airport noise disclosure, the estimates imply that the disclosure reduced housing prices by approximately 2.9% in the high noise zone. The total impact of airport noise in this zone is approximately 10.7% (obtained from column (3) by adding the coefficients on noise65_dum and noise65_post together). Therefore, the impact of the airport noise disclosure represents an approximate 37 percentage point increase in the implicit price estimate for the high noise zone.

It does not appear that the disclosure affected housing prices in the low noise zone. However it is important to acknowledge that this zone was defined using a generous delineation of the low noise area. It includes houses that are seldom, if ever affected by airport noise. One interpretation of the lack of an effect from the disclosure in the low noise zone is that the disclosure itself did not cause an "overreaction" effect. This interpretation stems from the fact that the low noise zone can be thought of as having received a disclosure "placebo." If changes in housing prices are simply a reflection of overreaction to the disclosure then one would expect an impact even in the low noise zone. However, an ideal experiment would administer disclosure "placebos" in comparable *high noise* areas as well, therefore the possibility that buyers are overreacting in high noise areas cannot be completely ruled out.

The reported results are directly relevant to the previous literature that has attempted to quantify the disamenity cost of airport noise. This study has demonstrated that the implicit price for airport noise is affected by the information available to buyers. This information effect suggests that some estimates from previous hedonic work on the impact of airport noise results may be bi-

[20] For example, the meta-analysis by Nelson [13] used estimates of the impact of airport noise from 33 published and unpublished studies and concluded that a change of 10 dB of noise would impact the value of a house by between 5 and 6 percent.

ased downwards.[21] The magnitude of this bias depends on how well-informed buyers are about a given airport. Buyers are likely to be better informed about airports that are large and have noise contour bands that spread out evenly in all directions. Studies on small to mid-size airports where distance to the airport is not a good proxy for airport noise are likely more prone to have a large information bias in the implicit price for airport noise.

6. Conclusion

The hedonic method has been an important tool for decomposing prices of attributes in a differentiated product. It has been widely used in urban economics to understand the value of a host of amenities and disamenities that are not traded explicitly in their own markets. However, the assumptions of full information and rational choice are required to interpret marginal implicit prices as marginal values. If buyers are incompletely informed about a given attribute (as suggested by recent disclosure policies in the housing market), then an attribute's quality will not be fully capitalized even when information for the attribute is publicly available.

The introduction of an airport noise disclosure in the residential housing market surrounding RDU was used as a quasi-random experiment to analyze the impact of asymmetric information about airport noise on housing prices. A primary result from the analysis in this study is that the airport noise disclosure appears to have increased the price discount for homes near the airport by 37 percentage points. This was interpreted as signaling that some buyers were *uninformed* about airport noise prior to the disclosure. Thus the level of buyer's information may partially explain differences in the estimates for the marginal value of airport noise previously reported in the literature. Furthermore these results suggest that when many buyers are uninformed, implicit price estimates from a conventional hedonic model may often represent a lower bound for how households truly value an urban disamenity. Thus the information bias described in this study may also help to explain why estimates for other spatial disamenities (i.e. air pollution, hazardous waste risks, etc.) are often quite heterogeneous. The recent proliferation of disclosure laws in the housing market and other differentiated product markets may provide other natural experiments amenable to empirical tests of how important buyer information is to market prices.

This study also suggests that it may be possible for policymakers to design information programs that help uninformed agents to acquire needed information that is already publicly available. The Raleigh–Durham Airport Authority apparently decided that the costs of implementing their noise disclosure were outweighed by the benefits of reducing their liability from future lawsuits. Understanding the costs and benefits of such programs represents another interesting avenue for future research.

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[21] Some airport noise papers seem to recognize that estimates might be biased given buyer information, but do not try to articulate the mechanism by which it occurs. For example, Espey and Lopez [6] estimated the impact of airport noise on houses surrounding the Reno–Tahoe International Airport and found houses in the 65 Ldn contour sold for approximately 2% less than comparable houses. Yet they admit that their estimates may be biased downward because the airport was expanding rapidly and "such growth may not have been anticipated at the time of purchase."

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