



The Impact of Airport Noise on House Prices

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Abstract

Using individual house sale data and the release of an airport noise contour map, the relationship between airport noise contours and house prices in Melbourne is studied. House prices are not related to noise contours but annual aircraft movements and distance from the runway are both identified as important determinants of the price of houses near the airport. Houses farther from the airport runway but with the same observable characteristics command a premium of up to 37 per cent which is likely attributable to a range of externalities from the nearby airport including airport noise. Results are robust to tests for time variation in airport disamenity values. The results suggest households use distance to the runway as a proxy for the effects of airport noise.

Keywords: House prices, Airport noise, Noise contour maps

JEL codes: R32, R41, D83, D62

1 Introduction

Governments, policy makers and regulators around the world are increasingly seeking to provide better information to consumers and other stakeholders to improve the efficiency of their choices. Examples can be found in health services (Hospital Compare in the USA and the Care Quality Commission in the UK), education (the school performance tables website in the UK and MySchool website in Australia) and transportation noise (the National Transportation Noise Map in the USA, [Bts.gov](https://www.bts.gov) 2017). In the real estate domain, the issue of information disclosure is studied for example by [Gatzlaff et al. \(2017\)](#) (hurricane mitigation) and [Pope \(2008\)](#) (airport noise). For most people, their home is a large investment and comprises most if not all their wealth. Information on the local amenity or disamenity of a potential home purchase can have major welfare effects.

In this paper, we empirically study how information from publicly available noise contour maps are incorporated into prices paid by homebuyers. The context is Essendon Airport, 10 km north-west of the central business district in Melbourne, Australia, a domestic airport with, on average, 150 daily aircraft movements. Using data on individual house sales between 1998 and 2013, along with individual property and suburb characteristics, we estimate a hedonic pricing model for properties that might be affected by noise from Essendon Airport. We first consider a model that incorporates information on each

property's location on the 2008 Australian Noise Exposure Forecast (ANEF) map of the area surrounding the airport, along with travel distance to the airport, annual aircraft movements and other property-related factors. Importantly, the 2008 ANEF map was the first Essendon Airport noise contour map that was widely disseminated on the internet through its inclusion in the 2008 Essendon Airport Master Plan ([Essendon Airport 2008](#)).¹ We use the release of this map as a form of exogenous variation in the availability of airport noise information regarding Essendon Airport which allows us to test for changes in the relationship between house price and noise contours after the release of the map. The key results are that house prices are uncorrelated with ANEF contours and that the relationship between price and ANEF contours does not change after the release of the 2008 ANEF map, though annual aircraft movements are found to have a strong negative relationship with house prices. While it is surprising that noise contour information is uncorrelated with house prices, it may be the case that it is too specialised or difficult to access or use for most homebuyers to incorporate into their home-buying decisions or that airport noise as reflected by the ANEF map is not a major concern for homebuyers.

Using straight line distance from the airport runway as an alternative measure of airport disamenity, we find a positive but nonlinear relationship between house price and distance to the runway while the relationship with annual aircraft movements is maintained. House sale prices rise with the distance from the runway after controlling for a range of property and neighbourhood characteristics. Compared to the homes closest to the runway (0.25 km), the maximum price premium is found to be 37 per cent at 1.64 km from the runway while the marginal effect of a reduction in annual aircraft movements of 1000 is 4.5 per cent (average aircraft movements are around 62,000 for the period studied). At a distance of 1.64 km, most houses are outside the outer noise contour (ANEF 20), but we can find many houses between the ANEF 20 and ANEF 25 noise contours. However, we argue part of the explanation for noise contours being uncorrelated with house price is that many houses in this area are much closer to the runway. A test of the price–distance relationship in this area confirms it is robust. Our results suggest, at such short distances, homebuyers might be inclined to believe that they will be affected by the airport because of its proximity, irrespective of the property's position on an ANEF map.

Recent studies by [Lawton and Fujiwara \(2016\)](#) and [Ozkurt, Hamamci, and Sari \(2015\)](#) reiterate the negative effects of airport noise on nearby residents. It is natural that changes in the externalities of airports such as noise would lead to changes in house prices.² It is also the case that houses in different locations relative to the airport will be more and less affected by airport noise as will the purchase price of those houses. Numerous studies have shown the negative effects of airport noise on house prices. [Nelson \(2004\)](#) provides a meta-analysis of the literature, showing discounts of between 0.50 and 0.90 per cent per decibel (dB) increase in noise.

In a study of the area around Amsterdam Airport, [Dekkers and van der Straaten \(2009\)](#) find discounts, relative to unaffected houses, of up to 13 per cent for houses experiencing aircraft noise in the 50–55 dB range, [McMillen \(2004\)](#) finds a 9 per cent discount for houses exposed to 65 dB or more airport noise around Chicago O'Hare airport, whereas [Cohen and Coughlin \(2008\)](#) find a 20.8 per cent discount for houses exposed to more than 70 dB of aircraft noise in the area around Atlanta Airport in the USA.³ Using the closure of Hellenikon International Airport in Athens, Greece, [Thanos, Bristow, and Wardman \(2015\)](#) find a nonlinear relationship, consistent with the logarithmic nature of the dB scale, between house price and airport noise, with discounts of 0.40 and 2.38 per cent per dB for houses exposed to noise exceeding 45 and 75 dB, respectively. Our finding of a non-linear relationship between house price and distance to the runway provides some support for the claim that distance may proxy for the effects of airport noise on house price.

The result that house prices are uncorrelated with ANEF contours but are correlated with straight line distance to the runway has at least two explanations. First, relative to airport noise, homebuyers may be more concerned with air pollution, road congestion, visual

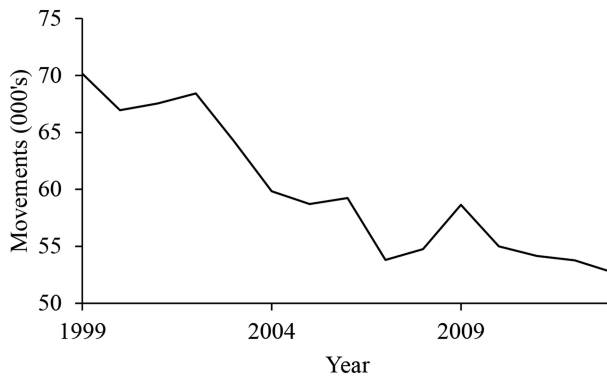


Figure 1. Aircraft movements at Essendon Airport, 1999–2013. (Source: [Airservices Australia 2018](#))

presence and other possible disamenities of the airport that might be correlated with distance to the runway. A second explanation is that of imperfect information in this real estate market where buyers are either unaware of the specialised noise contour information or struggle to find or incorporate the information into their decision. This relates to the work of [Pope \(2008\)](#) who shows the price discount on airport noise-affected properties increased from 7.8 to 10.7 per cent after the introduction of mandatory disclosure laws in North Carolina in 1996, implying that homebuyers did not fully incorporate the effects of airport noise into their buying decisions and ultimately the home price. Given this important result and the large literature that points to the negative impact of airport noise on house price, we focus on this latter interpretation, where buyers are likely to care about potential airport noise, along with other airport externalities, and take a rule of thumb approach, focusing on the straight line distance to the runway as a proxy for both noise and other effects of the nearby airport.

In the next section, we provide some key details of Essendon Airport and the surrounding area. In [Section 3](#), we describe the noise contour and distance data that are the focus of our analysis. We also explain the house price and characteristics data used, providing summary statistics. The empirical approach, results and a series of robustness tests are presented in [Section 4](#) with conclusions presented in [Section 5](#).

2 Essendon Airport background

Essendon Airport is located 10 km north-west of the Melbourne central business district (CBD) in Victoria. It was set up in 1919 and became Australia's second international airport in 1950. At that time, it was Melbourne's only airport. However, as air travel grew in popularity, the airport was not suitable for larger aircraft, such as the Boeing 707, and an alternative was developed. In 1970, international flights were routed away from Essendon Airport and instead through Melbourne Airport, 19 km north-west of the Melbourne CBD.⁴

The period for which we study the impact of the airport on house prices, 1998–2013, is long after international flights ceased. Over this period, Essendon Airport served as a domestic airport, hosting regular passenger transport to regional locations, charter and tourist flights, emergency services flights (including helicopters), freight and private aircraft. [Fig. 1](#) shows the number of aircraft movements has declined gradually since 1999. Some variability in movements is a result of the airport's emergency services role which includes Victorian Police Air Wing and Air Ambulance services; for example, the 6 per cent increase in movements in 2009 is related to the major Victorian bushfires in that year and the resultant increase in emergency services use of the airport. All these services combine to over 50,000 aircraft movements per annum, or close to 150 movements per day on average.⁵ As a

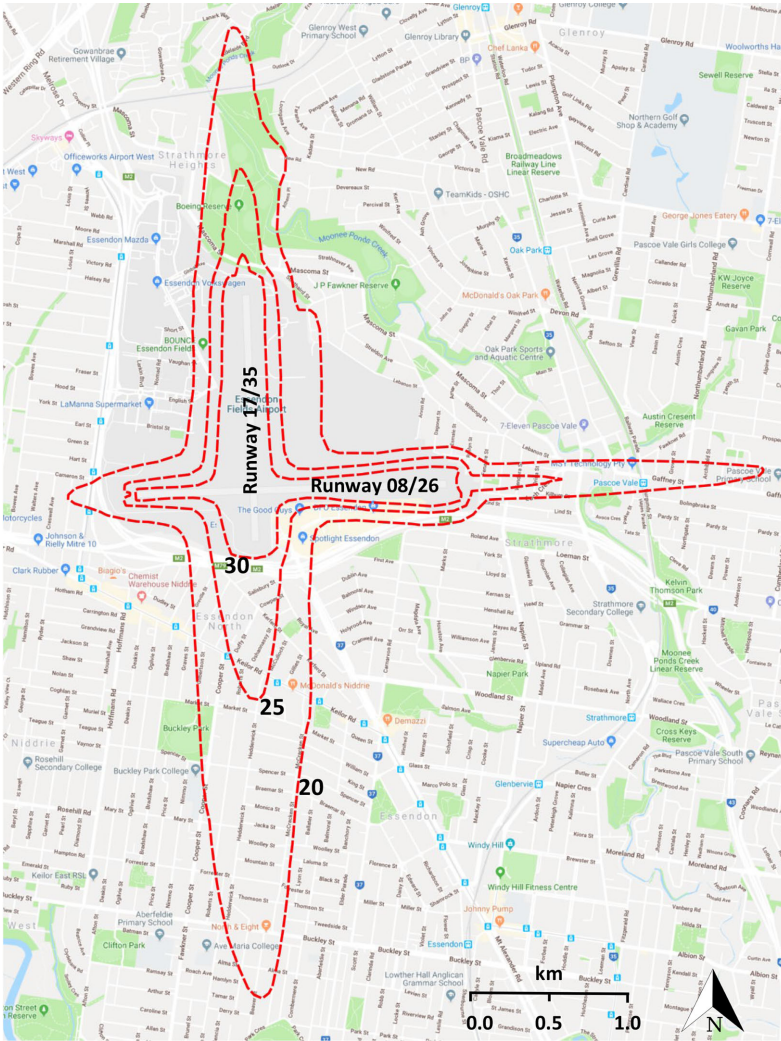


Figure 2. Australian noise exposure forecast (ANEF) 2008 contours for Essendon Airport. (Source: Map created using the Free and Open Source QGIS. Map data © 2019 Google. Noise contours based on ANEF contours in [Essendon Airport 2008: 38](#))

consequence, Essendon Airport has the potential for a significant impact on the amenity of nearby residents.

As can be seen from Fig. 2, the airport comprises two runways. Runway 17/35 is a 1.5 km north-south oriented runway while runway 08/26 is a 1.9 km east-west oriented runway. This study focuses on the suburbs to the south of runway 17/35 because, as illustrated in Fig. 2, the noise contours at the southern end of runway 17/35 have a large overlap with the surrounding suburbs and residential properties while nearly 70 per cent of movements use runway 17/35. Conversely, the noise contours to the east of runway 08/26 overlap with a relatively small number of residential properties and a small fraction of runway 08/26 take-offs occurs at the eastern end of that runway. The noise contours at the western end of runway 08/26 and the northern end of runway 17/35 comprise industrial areas and nature reserves, respectively.⁶

These properties are also separated from the airport by a freeway. To the south of the airport, the freeway has a lower elevation than neighbouring suburbs which are protected by high walls (or noise barriers) serving to minimise the noise effects of the freeway. Notwithstanding this, we anticipate continuous freeway noise will have a qualitatively different effect to intermittent airport noise and thus control for proximity to the freeway in our analysis with an indicator variable defined below; see [Andersson, Jonsson, and Ögren \(2010\)](#) for a similar example, distinguishing rail and freeway noise.

3 Data

To study the impact of airport and aircraft noise on house prices, our analysis brings together data on house sales and characteristics, airport noise contours, distance from runway and neighbourhood characteristics. We explain these data in turn below.

3.1 Impact of the airport

Our approach to measuring the impact of the airport on surrounding suburbs is to use publicly available ANEF maps. These contour maps classify areas surrounding airports according to the extent and intensity of aircraft noise exposure. The ANEF is similar to the Noise Exposure Forecast (NEF) used internationally. One key difference is that higher-impact, night-time noise is evaluated between 7 p.m. and 7 a.m. with the ANEF, whereas it is evaluated between 10 p.m. and 7 a.m. with the NEF.⁷

ANEF contour maps are typically prepared by airport owners or operators and endorsed by Airservices Australia, an Australian Government-owned corporation. These contour maps are included in the master plan of each major airport and are used by local government authorities for planning purposes. The contours take into account forecast changes in aircraft movements, audible frequencies of those movements, and the daily distribution of movements with night-time movements multiplied by four; see [Essendon Airport \(2013: 35\)](#) for more detail. Our analysis is based on the noise contour map from the 2008 Essendon Airport Master Plan, redrawn using QGIS software and presented in Fig. 2. This was the first Essendon Airport noise contour map that was widely available to the public on the internet, published in October 2008. Given our period of analysis ranges from 1998 to 2013, the 2008 ANEF map provides a ‘treatment’ period from 2009–2013, for which we can identify the effects of this new public information about the impact of the airport on house prices after its release.

The map classifies areas around the airport into the following four contour zones to describe the noise pollution in the area:

- Under 20 ANEF units—noise levels are considered to be insignificant.
- Between 20 and 25 ANEF units—noise levels begin to have a detrimental impact.
- Between 25 and 30 ANEF units—effects become progressively more severe and typically preclude new developments involving residential accommodations, schools, universities and hospitals.
- Above 30 ANEF units—the highest noise impact around Essendon Airport, where residential development is unacceptable for planning purposes.⁸

As can be seen in the contour map in Fig. 3, we allocate each house sold (denoted by the grey dots in the map) into the area between the relevant noise contours, creating an ordinal variable to reflect airport noise in the estimation. The 2008 ANEF map shows no properties lie within the ANEF 30 noise contour. Of the 1,230 house sales in our sample, 163 lie between the ANEF 25 and 30 contours and 577 lie between the ANEF 20 and 25 contours, while the remaining 490 are outside the ANEF 20 contour but within 200 m of

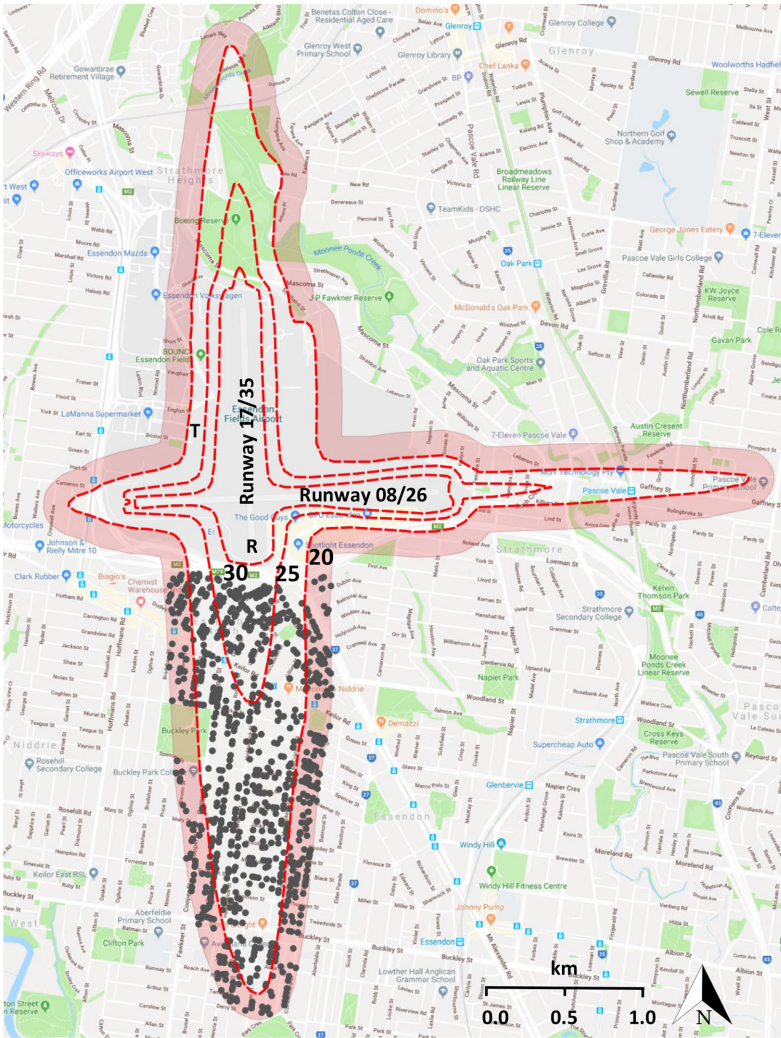


Figure 3. Properties sold between 1998 and 2013 in the area of the 2008 ANEF contours for Essendon Airport. Shaded area outside ANEF 20 contour is a 200-m buffer zone. Map created using the Free and Open Source QGIS. Map data © 2019 Google. Noise contours based on ANEF contours in [Essendon Airport 2008](#): 38.

this contour. This 200-m buffer zone focuses attention on houses that are unaffected by airport noise but most similar to those inside the ANEF 20 contour.

We complement the noise contour data described above with the straight line distance to the runway as an alternative measure of disamenity due to airport proximity. We consider this alternative measure because of its potential to capture other aspects of airport disamenity such as air pollution and visual presence, in addition to noise effects. The straight line distance also offers a simple rule of thumb measure that may be used by homebuyers who may not understand or be aware of the more sophisticated noise contour maps available to the public.

It is consistent with the hedonic pricing literature on the value of nearby amenities such as schools, public transport facilities or parks; see, for example, [Song and Knapp \(2003\)](#) and [Tyrväinen and Miettinen \(2000\)](#) for valuing amenities and [Michaels and Smith \(1990\)](#)

for disamenities. It was measured using Google Maps. The measurement was automated in Microsoft Excel and calculated using the latitude and longitude of both the southern end of runway 17/35 (denoted as point R in Fig. 3) and the address of each property sold (each grey dot in Fig. 3).

Linear distance to the airport entrance or terminal is typically used in the airport disamenity literature to capture airport access which is a measure of positive aspects of airport proximity such as the convenience of access and nearby employment opportunities; [Cohen and Coughlin \(2008\)](#), [Pope \(2008\)](#) and [Tomkins *et al.* \(1998\)](#) find airport access adds value to a property, though [Espey and Lopez \(2000\)](#) find the opposite. However, Essendon Airport is separated from the affected suburbs by a freeway. As a consequence, the shortest car travel distance differs from the often-used straight line distance to the terminal. The former is also measured using Google Maps and Microsoft Excel, calculating the shortest road travel distance between the addresses of the Essendon Airport terminal (denoted as point T in Fig. 3) and each property sold (each grey dot in Fig. 3).

3.2 House prices and characteristics

House prices are based on data for all sales in the area under study from 1 January 1998 to 30 June 2013, provided by the Valuer-General Victoria. Freestanding and semi-detached houses were included in the estimating sample.⁹ Key components of the data include the price paid for the house, size of the land and a built area of the house, number of bedrooms and age of house at sale date.¹⁰

House prices were inflation adjusted to a base period of the December quarter of 2012 using quarterly Consumer Price Index data for Melbourne from the [Australian Bureau of Statistics \(2016\)](#). Thus, all prices are in real 2012 December quarter Australian dollars. In addition, quarterly time fixed effects based on sale date are included to control for any time effects on prices not accounted for by consumer price inflation. As house sales in the sample range from 1 January 1998 to 30 June 2013, this amounts to 62 quarter indicators with the first quarter omitted as the base category.

The properties studied fall into one of the four suburbs (Aberfeldie, Essendon, Essendon North and Strathmore). Suburb indicators are included to control for a range of suburb characteristics. Another important aspect of house values in Melbourne is access to public schools. In metropolitan Melbourne, students are entitled to attend their designated neighbourhood school as measured by the straight line distance for their permanent address, thereby defining local school zones. We compute the straight line distance and construct an indicator for the designated neighbourhood public primary school for each property. In turn, this provides another measure of a widely accepted important local neighbourhood characteristic that may influence house value; see for example [Black \(1999\)](#).¹¹ Access to public transport is another important local amenity. The properties being studied are located close to the Craigieburn train line, providing access to the Melbourne CBD within 16–23 minutes during peak hours. For each property, we compute and include the distance to the nearest train station to control for any benefits (or costs) arising from proximity to these stations.

In addition to these local neighbourhood characteristics, we also control for proximity to the freeway with an indicator for all houses within 200 meters of the freeway; a similar approach is used by [Andersson, Jonsson, and Ögren \(2010\)](#) when distinguishing road noise from a nearby motorway and intermittent railway noise. Despite efforts to minimise the impacts of freeway noise, we anticipate proximity to the freeway to have a negative effect on house price.

3.3 Summary statistics

Table 1 provides summary statistics of the sale price and property characteristics, including straight line and travel distances to Essendon Airport. Overall average characteristics

Table 1. Summary statistics by ANEF contour areas and for full sample ($N = 1230$).

House characteristics	ANEF 25–30 ($N = 163$)		ANEF 20–25 ($N = 577$)		Outside ANEF 20 ($N = 490$)		All properties ($N = 1230$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Real house price (\$000's)	515.015	239.989	809.748	428.459	688.659	346.819	722.451	388.881
ANEF noise contour								
25–30 (1/0)	-	-	-	-	-	-	0.133	-
20–25 (1/0)	-	-	-	-	-	-	0.469	-
outside 20 (1/0)	-	-	-	-	-	-	0.398	-
Straight line distance	0.435	0.157	1.386	0.651	1.572	0.721	1.334	0.735
runway 17/35 (km)								
Travel distance airport (km)	3.202	0.247	4.139	0.956	4.360	0.966	4.103	0.970
Block size (m ²)	572.945	262.000	751.929	245.853	626.912	254.212	678.407	261.074
Built area (m ²)	142.953	67.642	210.307	104.317	173.629	81.453	186.770	94.481
Construction (weatherboard)	0.245	-	0.319	-	0.390	-	0.337	-
Semi-detached house	0.135	-	0.121	-	0.153	-	0.136	-
Bedrooms	2.724	0.696	3.182	0.837	2.965	0.773	3.035	0.810
Suburb Aberfeldie	0.000	-	0.088	-	0.133	-	0.094	-
Essendon	0.049	-	0.698	-	0.543	-	0.550	-
Essendon North	0.951	-	0.213	-	0.227	-	0.316	-
Strathmore	0.000	-	0.000	-	0.098	-	0.039	-
Freeway	0.497	-	0.081	-	0.169	-	0.172	-
Primary School								
Aberfeldie	0.000	-	0.314	-	0.443	-	0.324	-
Essendon North	1.000	-	0.686	-	0.478	-	0.645	-
Strathmore	0.000	-	0.000	-	0.080	-	0.032	-
Distance to the nearest train station	2.056	0.116	1.691	0.317	1.554	0.437	1.685	0.387
Age of house ($N = 150,470, 439,1059$)	43.947	23.953	46.357	27.559	51.401	28.192	48.107	27.430

Notes: All property characteristics based on Valuer-General Victoria property sales data. House prices in real Australian dollars (base December quarter 2012), using [Australian Bureau of Statistics \(2016\)](#).

are shown in the final two columns. The average house in our sample has a block size of 678 square meters, 3 bedrooms, was 1.33 km from runway 17/35, 4.10 km travel distance to Essendon Airport and sold for \$722,000 (CPI adjusted to December 2012). The distribution of house sales across ANEF noise contour areas was about 13 per cent in the highest noise area (ANEF 25–30), 47 per cent in the ANEF 20–25 area and 40 per cent outside the ANEF 20 contour. The average built area was 187 square meters with 14 per cent of the properties being semi-detached houses, 34 per cent were of weatherboard (wooden) construction and the remainder of brick construction, while the average distance to the nearest train station is 1.69 km. The properties studied here are mostly in the Aberfeldie (9 per cent), Essendon (55 per cent) and Essendon North (32 per cent) suburbs. For most properties, the local primary school is either Essendon North (65 per cent) or Aberfeldie (32 per cent). The average house age at the time of sale is 48 years.

We also present in Table 1, summary statistics by noise contour areas to illustrate differences between the different areas around the airport. The first pair of columns present means and standard deviations for houses between the ANEF 25 and 30 contours. These are the sample houses that will experience the greatest level of airport noise. The second pair of columns present these statistics for houses between the ANEF 20 and 25 contours while the third pair of columns present characteristics of houses in our sample that lie outside the ANEF 20 contour. Houses will be exposed to less extreme airport noise as we move to lower ANEF areas, while houses in the ‘Outside ANEF 20’ column of Table 1 should experience acceptable levels of airport noise from Essendon Airport.

Average prices rise from \$515,000 to \$810,000 as we move from ANEF 25–30 to ANEF 20–25 but fall back to \$689,000 outside the ANEF 20 contour. These differences may be related to block size and built area which are on average highest in the ANEF 20–25 area; however, the price pattern persists after controlling for these characteristics in the noise contour modelling below. Other notable features are that average straight line distance is greater in the lower ANEF areas, but travel distance is similar between the ANEF 20–25 and outside the ANEF 20 contours but is lower for properties between the ANEF 25–30 contours. The freeway is closest to properties between the ANEF 25–30 contours with 50 per cent within 200 meters. This fraction falls to 8 per cent for houses in the ANEF 20–25 area and 17 per cent for houses outside the ANEF 20 contour.

4 Methodology and results

We estimate a hedonic price model that incorporates both individual property and locational characteristics. The key idea of this approach is that house values are a composite of these various characteristics.¹² In our case, one of these characteristics is the location relative to the airport. The baseline model estimated incorporates noise contour information and is given by:

$$\log(P_{i,t}) = \beta_0 + \beta_1 N_i^{25} + \beta_2 N_i^{20} + \beta_3 X_{i,t} + \beta_4 Q_t + \varepsilon_{i,t} \quad (1)$$

where $P_{i,t}$ is the price that house i sold for in period t , N_i^{25} and N_i^{20} are indicators of a property’s position in the ANEF 20–25 area and outside the ANEF 20 contour, respectively, with the omitted category being properties within the ANEF 25–30 area. A range of property characteristics such as travel distance to the airport, $\log(\text{block size})$, $\log(\text{built area})$, construction type (weatherboard/brick), type of house (free-standing/semi-detached), number of bedrooms, freeway proximity and distance to the nearest train station are included in $X_{i,t}$. We also include a suburb indicator which serves as a suburb fixed effect, to capture variation in suburb-specific characteristics and amenities.¹³ An indicator for local primary school is included to capture the impact on house prices of such sought after local amenities. While we have controlled for inflation, we expect that other aggregate factors that vary over the business cycle such as interest rates, economic growth and unemployment to affect

prices over time. To account for this, quarterly time-fixed effects (Q_t) are included, while the disturbance term $\varepsilon_{i,t}$ is assumed to have zero mean and constant variance.

The model is also estimated with the noise contour information replaced with distance to the runway as follows:

$$\log(P_{i,t}) = \delta_0 + \delta_1 D_i + \delta_2 (D_i)^2 + \delta_3 X_{i,t} + \delta_4 Q_t + e_{i,t} \quad (2)$$

where D_i measures airport disamenity by the straight line distance from property i to runway 17/35 and is included as a second-order polynomial. Other variables are as already defined while $e_{i,t}$ is a zero mean, constant variance error term.

The models in (1) and (2) are estimated using OLS with standard errors clustered by street to account for any spatial dependence. While house prices have been transformed by taking logarithms, the specification incorporates linear and logarithmic explanatory terms. The coefficients on logarithmic explanatory variables are elasticities and should be interpreted as the average percentage change in house price for a 1 per cent change in the explanatory variable. For linear explanatory variables, coefficients provide a measure of the average percentage change in house price for a one-unit change in the explanatory variable.

While noise contours are expected to capture the effects of aircraft noise, they are static and do not incorporate the evolution of air traffic over time, reflected in Fig. 1. To incorporate air traffic dynamics, we also estimate the models in Equations (1) and (2) with the inclusion of annual aircraft movements at Essendon Airport. The approach is to include annual aircraft movements as an additional control and to consider the interaction of this variable with the noise contour variables and distance variables to test if the impact of airport noise on house prices evolves with annual aircraft movements. The inclusion of this additional variable focuses on an important mechanism through which the airport might affect property values; greater annual movements are likely to lead to greater noise effects on properties near the airport. Importantly, this additional analysis takes advantage of the temporal variation in annual aircraft movements to identify and test the stability of the relationship between property location, given by ANEF area or distance to the runway, and house price which might otherwise be captured by the included quarterly time-fixed effects.

We further extend our empirical identification strategy by taking advantage of the release of the 2008 Essendon Airport Master Plan. As location on the ANEF contour map is expected to be more strongly correlated with house price after the publication of the 2008 master plan, we construct an indicator for sales after the release of the master plan and interact it with the included noise contour indicators. The model estimated is given by:

$$\log(P_{i,t}) = \gamma_0 + \gamma_1 N_i^{25} + \gamma_2 N_i^{20} + \gamma_3 N_i^{25} Post_i + \gamma_4 N_i^{20} Post_i + \gamma_5 X_{i,t} + \gamma_6 Q_t + \xi_{i,t}, \quad (3)$$

where the variable $Post_i$ is an indicator of whether property i was sold after the ANEF contour map was released in 2008. Other variables are as defined above and $\xi_{i,t}$ is the standard disturbance term. In this specification, γ_1 compares the sale price of properties in the ANEF 20–25 area to those in the ANEF 25–30 area before the release of the ANEF contour map, while $(\gamma_1 + \gamma_3)$ reflects the same comparison after the release of the map. The parameter γ_3 then reflects the difference in these differences and provides a test of the impact of the release of the information contained in the 2008 ANEF contour map on house prices. The parameter γ_4 provides a similar comparison for properties outside the ANEF 20 contour with those in the ANEF 25–30 area. The model in Equation (3) is also extended through the inclusion of annual aircraft movements interacted with noise contour area indicators both before and after the release of the 2008 Essendon Airport master plan, adding the temporal variation in movements to strengthen the identification of the effect of the release of the master plan.

4.1 Results

Parameter estimates for several alternative specifications of the models incorporating noise contours are presented in Table 2, with standard errors clustered by street in parentheses. Models (1) and (3) in Table 2 are versions of the specification in Equation (1) and include a range of property characteristics, suburb, freeway and local public school indicators, distance to the closest train station and time-fixed effects, with model (3) adding annual aircraft movements along with interactions with noise contour indicators.¹⁴ Models (2) and (4) in Table 2 are versions of the specification in Equation (3), adding to models (1) and (3), respectively interactions between the noise contour variables (including those interacted with movements) and an indicator for sales occurring after 2008 when the master plan was made publicly available. Each of these specifications provides qualitatively similar results and a statistically strong explanation for house prices with R^2 ranging between 0.701 and 0.703.

The omitted noise contour area for each of these models is that closest to the runway, the ANEF 25–30 area. House prices are expected to increase as the intensity of airport noise decreases, implying a positive coefficient for the ANEF 20–25 area, increasing further for the area outside the ANEF 20 contour. Model (1) shows that after controlling for a range of property characteristics houses in the ANEF 20–25 area sell at a premium of around 7 per cent to those in the ANEF 25–30 area, though these differences are imprecisely estimated and significant only at the 10-per cent level. However, houses outside but within 200 meters of the ANEF 20 contour sell for on average 2.4 per cent more than those in the ANEF 25–30 area, a difference that is not statistically significant. Model (3) adds movements to model (1) interacting it with the noise contour indicators. Given the interactions, average marginal effects for the ANEF 20–25 and ANEF 20 contour indicators and movements are computed. These marginal effects are respectively 0.070 (P -value = 0.068), 0.026 (P -value = 0.544) and -0.028 (P -value = 0.000). These results imply that aircraft movements are an important determinant of house prices with prices falling 2.8 per cent with a 1000 flight increase in movements. Importantly the effects of noise contour indicators are qualitatively unchanged.

A potentially stronger result is expected from models (2) and (4), where the effects of the noise contour areas are allowed to differ before and after the release of the 2008 Essendon Airport master plan and the ANEF contour map contained therein. It is expected that the baseline parameters will be smaller and the interaction terms would be larger, both relative to the ANEF indicators in models (1) and (3). In model (2), the price premium in the ANEF 20–25 area is found to increase from 5.8 to 11.4 per cent ($5.8 + 5.6$) after the release of the 2008 master plan but these estimates are statistically insignificant. The price premium in the area outside the ANEF 20 contour falls after the release of the 2008 master plan but again these estimates are not statistically significant.

The pattern is similar to model (4) where annual aircraft movements are included and interacted with the noise contour indicators. Given the various interactions in this model, average marginal effects are computed for the ‘ANEF 20–25’ and ‘outside 20’ contour indicators and the ‘ANEF 20–25 \times After 2008’ and ‘outside 20 \times After 2008’ interactions. These marginal effects are 0.062 (P -value = 0.155), 0.031 (P -value = 0.517), 0.172 (P -value = 0.264), and -0.017 (P -value = 0.912), respectively, implying no statistically significant effects of the release of the 2008 master plan. The average marginal effect of annual aircraft movements is -0.027 (P -value = 0.000), implying the effect of aircraft movements is qualitatively unchanged from the results in the model (3).

The parameter estimates on ‘ANEF 20–25 \times After 2008’ and ‘outside 20 \times After 2008’ in Table 2 correspond to γ_3 and γ_4 in Equation (3). The difference in the difference between house prices in the ANEF 25–30 and ANEF 20–25 areas compared before and after the release of the noise contour map in 2008 is given by γ_3 with insignificant estimates of 0.056 for model (2) and 0.172 for model (4), implying the release of the contour map did not change the price difference between these two areas. The equivalent difference in the

Table 2. Parameter estimates for models of the relationship between log(house price) and 2008 ANEF contours for Essendon Airport. Model (1) includes property and neighbourhood characteristics along with quarterly time-fixed effects. Model (2) adds an interaction between the noise contour variables and an indicator for sales occurring after the release of the 2008 master plan. Models (3) and (4) add annual aircraft movements which is interacted with noise contour variables to models (1) and (2) respectively.

Variables	(1)	(2)	(3)	(4)
ANEF (25–30 omitted)				
20–25	0.069* (0.038)	0.058 (0.043)	0.256 (0.219)	0.201 (0.294)
20–25 × Movements			−0.003 (0.004)	−0.002 (0.005)
Outside 20	0.024 (0.042)	0.036 (0.047)	−0.201 (0.258)	−0.164 (0.359)
Outside 20 × movements			0.004 (0.004)	0.003 (0.006)
Movements (000’s)			−0.028*** (0.005)	−0.030*** (0.005)
ANEF 20–25 × after 2008		0.056 (0.057)		−1.218 (1.082)
ANEF 20–25 × after 2008 × Movements				0.023 (0.020)
Outside 20 × after 2008		−0.036 (0.050)		0.026 (1.080)
Outside 20 × after 2008 × Movements				−0.001 (0.020)
Airport access	−0.338 (0.204)	−0.360* (0.203)	−0.349* (0.205)	−0.363* (0.202)
(Airport access) ²	0.049** (0.023)	0.052** (0.023)	0.051** (0.024)	0.052** (0.023)
log(<i>block size</i>)	0.220*** (0.035)	0.220*** (0.036)	0.223*** (0.037)	0.223*** (0.036)
log(<i>built area</i>)	0.239*** (0.033)	0.241*** (0.033)	0.240*** (0.033)	0.240*** (0.033)
Weatherboard (brick omitted)	0.037 (0.023)	0.036 (0.023)	0.036 (0.022)	0.036 (0.023)
Semi-detached house	−0.315*** (0.044)	−0.314*** (0.044)	−0.316*** (0.044)	−0.316*** (0.044)
Bedrooms (two omitted)				
Three	0.162*** (0.033)	0.163*** (0.033)	0.162*** (0.032)	0.162*** (0.032)
Four	0.219*** (0.050)	0.220*** (0.049)	0.219*** (0.050)	0.218*** (0.050)
Five	0.306*** (0.049)	0.303*** (0.048)	0.302*** (0.048)	0.299*** (0.048)
Six+	0.003 (0.202)	−0.007 (0.207)	−0.015 (0.207)	−0.021 (0.206)
Suburb (Essendon omitted)				
Aberfeldie	−0.235*** (0.080)	−0.235*** (0.082)	−0.234*** (0.083)	−0.236*** (0.082)
Essendon North	−0.095** (0.040)	−0.092** (0.040)	−0.094** (0.041)	−0.092** (0.041)
Strathmore	−0.187** (0.082)	−0.188** (0.082)	−0.190** (0.087)	−0.189** (0.084)
Freeway	−0.052 (0.049)	−0.050 (0.048)	−0.050 (0.048)	−0.049 (0.048)

Table 2. Continued

Variables	(1)	(2)	(3)	(4)
Primary school (Aberfeldie omitted)				
Essendon North	-0.014 (0.028)	-0.014 (0.029)	-0.013 (0.028)	-0.015 (0.029)
Strathmore	0.155* (0.081)	0.156* (0.080)	0.156* (0.085)	0.157* (0.081)
Distance to train	0.617*** (0.227)	0.639*** (0.233)	0.637*** (0.236)	0.654*** (0.236)
(Distance to train) ²	-0.190** (0.072)	-0.200*** (0.074)	-0.196** (0.075)	-0.202*** (0.075)
Constant	10.189*** (0.508)	10.212*** (0.506)	12.178*** (0.638)	12.314*** (0.654)
Quarterly time-fixed effects	Yes	Yes	Yes	Yes
Observations (N)	1,230	1,230	1,230	1,230
R ²	0.701	0.702	0.702	0.703

Note: *, ** and *** denote 10, 5 and 1 per cent level of significance, respectively.

difference between the ANEF 25–30 and the area outside the ANEF 20 contour is given by γ_4 with unexpectedly negative but statistically insignificant estimates.

The results in Table 2 imply that the price of houses south of Essendon Airport are not correlated with the ANEF contour areas within which they lie. This result suggests homebuyers are not concerned by airport noise reflected in the 2008 ANEF contour maps. Even if homebuyers were aware of the contour map information in the years before the release of the master plan, we would expect to see stronger differences for model (1) and (3) in Table 2. The result might be due to homebuyer concerns with aspects of runway proximity other than airport noise, for which the ANEF noise contours may not provide good information. This might include the visual impact of the airport, air quality, traffic, risk of an air crash, or other environmental conditions; all factors expected to reduce the price of houses closer to the airport.¹⁵ Conversely, homebuyers may be unaware of noise contour maps when making a decision to purchase a home in the area as there is no regulatory requirement for the master plan or maps to be disclosed to homebuyers. If they are aware, they may struggle to make use of the maps or to identify the location of their potential home on the maps—these maps do not include street names. A bounded rationality argument could be used to justify homebuyer use of a simpler measure of the effects of the nearby runway.

For these alternative explanations, we expect proximity to the airport runway to be negatively related to house price. As a consequence, models from Table 2 are re-estimated with noise contour indicators replaced with a quadratic function of straight line distance to the runway as specified in Equation (2) with annual aircraft movements entering linearly and interacted with distance to the runway in models (2) and (3), respectively.¹⁶ The parameter estimates for this alternative approach are presented in Table 3 with standard errors clustered by street in parentheses. The pattern of results for these specifications is similar to that observed for the noise contour models presented in Table 2, with the R^2 of around 0.703 for all three specifications. However, the critical difference is with the effects of distance to the runway.

Estimates for both the linear and squared terms of straight line distance are significant at the 1 per cent level for model (1) while the average marginal effect of distance (in km) is 9.9 per cent with a P -value of 0.005. These estimates imply that houses farther from the airport runway sell at a premium. Compared to houses closest to the runway (0.247 km), a house with identical observable characteristics but 1.64 km from the runway would sell for 36.8 per cent more; this is where the distance effect is at its maximum. The effect of the

Table 3. Parameter estimates for models of the relationship between log(house price) and distance to Essendon Airport runway 17/35. Model (1) includes a quadratic function of straight line distance to the runway, property and neighbourhood characteristics along with quarterly time-fixed effects. Model (2) adds annual aircraft movements which is interacted with distance to the runway variables in model (3).

Variables	(1)	(2)	(3)
Distance to runway	0.529*** (0.155)	0.536*** (0.144)	1.639*** (0.593)
Distance to runway × movements			−0.018** (0.009)
(Distance to runway) ²	−0.161*** (0.053)	−0.163*** (0.046)	−0.566*** (0.219)
(Distance to runway) ² × movements			0.007** (0.003)
Movements (000's)		−0.045*** (0.005)	−0.035*** (0.006)
Airport access	−0.550* (0.228)	−0.557*** (0.176)	−0.566* (0.229)
(Airport access) ²	0.074*** (0.026)	0.075*** (0.020)	0.076*** (0.026)
log(<i>block size</i>)	0.224*** (0.033)	0.224*** (0.025)	0.225*** (0.026)
log(<i>built area</i>)	0.237*** (0.034)	0.237*** (0.027)	0.238*** (0.030)
Weatherboard (Brick omitted)	0.030 (0.023)	0.029 (0.021)	0.029 (0.022)
Semi-detached house	−0.316*** (0.042)	−0.317*** (0.032)	−0.316*** (0.034)
Bedrooms (Two omitted)			
Three	0.167*** (0.033)	0.167*** (0.024)	0.169*** (0.030)
Four	0.224*** (0.051)	0.223*** (0.034)	0.221*** (0.040)
Five	0.311*** (0.051)	0.311*** (0.048)	0.307*** (0.051)
Six+	−0.017 (0.214)	−0.016 (0.141)	−0.023 (0.158)
Suburb (Essendon omitted)			
Aberfeldie	−0.134* (0.080)	−0.134* (0.072)	−0.136* (0.075)
Essendon North	0.006 (0.057)	0.008 (0.047)	0.009 (0.053)
Strathmore	−0.121 (0.080)	−0.119 (0.112)	−0.113 (0.077)
Freeway	0.024 (0.056)	0.024 (0.044)	0.023 (0.053)
Primary school (Aberfeldie omitted)			
Essendon North	−0.014 (0.037)	−0.013 (0.042)	−0.007 (0.040)
Strathmore	0.031 (0.091)	0.030 (0.127)	0.034 (0.093)
Distance to train	0.865*** (0.266)	0.865*** (0.241)	0.890*** (0.284)
(Distance to train) ²	−0.256*** (0.087)	−0.256*** (0.013)	−0.263*** (0.092)
Constant	10.031*** (0.475)	13.302*** (0.527)	12.668*** (0.537)
Quarterly time-fixed effects	Yes	Yes	Yes
Observations	1,230	1,230	1,230
R ²	0.703	0.703	0.704

Note: *, ** and *** denote 10, 5 and 1 per cent level of significance, respectively.

runway remains positive but decreases to 25.7 per cent for the houses at the 90th percentile of distance from the runway in our estimating sample (2.37 km).

Results are similar for model (2) which adds annual aircraft movements to model (1). The average marginal effect of distance (in km) is 10.2 per cent with a P -value of 0.001 and relative to the closest houses to the runway, the premium for a house 1.64 km from the runway 37.3 per cent. The important additional result here is that aircraft movements have a statistically significant impact on house prices after controlling for distance to the runway, with 1000 fewer movements raising house price by 4.5 per cent (P -value = 0.000).

Model (3) incorporates interactions between distance from the runway and movements. Results are statistically significant and consistent with intuition, suggesting the negative effects of proximity to the airport on house price are mitigated by reductions in aircraft movements. Given the interaction terms, we compute average marginal effects. The average marginal effect of annual aircraft movements for houses closest to the runway is computed to be 3.2 per cent (P -value = 0.045) while for those 1.64 km from the runway it is 3.9 per cent (P -value = 0.018). At the higher value of aircraft movements of 70,000 from the earlier years in our sample, the average marginal effect of distance is 14.4 per cent (P -value = 0.021) while at movements of 55,000 from the later years in the sample, the average marginal effect of distance is 13.1 per cent (P -value = 0.017).

The estimated quadratic relationship between price and distance to the runway is consistent with the lower, though statistically insignificant, positive coefficients on the outside ANEF 20 indicator variable in Table 2, suggesting the more detailed information in the continuous distance variable relative to the ANEF contour indicators may be aiding the estimation of the relationship.

These results are important because they show that while variation in house prices is not explained by ANEF noise contours, prices do increase for houses located farther from the airport runway. The implication is that homebuyers focus on either a simpler measure of the effects of airport proximity, that is, distance, or they are concerned with more than just noise from the airport which may be better reflected by distance than noise contours.

Focusing on houses between 1.6–1.8 km from the runway, they can be found in both the ANEF 20–25 area and outside the ANEF 20 noise contour. However, it appears the key reason that noise contours do not have a strong relationship with house prices is that many houses outside the ANEF 20 contour are closer than 1.64 km to the runway, with some less than 0.50 km away. Notwithstanding the fact that these houses should not experience excessive airport noise according to the ANEF contour maps, buyers seem to be guided by distance when deciding on the disamenity of the nearby airport and what they should pay for such houses.

We can estimate the economic impact of the discrepancy between distance and noise contours by comparing two properties that are outside ANEF 20 contour and thus *unaffected* by airport noise but at different distances from the airport. For example, according to model (3) in Table 3, at the average level of aircraft movements, properties 0.50 km from the runway sell at a 15.4 per cent discount to those in the same noise contour area with identical observed characteristics but 1.64 km from the runway. From Table 1, the average house price outside the ANEF 20 contour is \$688,659, implying houses closer to the runway in this notionally unaffected zone may be underpriced by as much as \$106,000 after controlling for a range of important observed characteristics.

While the focus of our study is on the impact of airport noise and how that is reflected in house price, for the other control variables included in the model, all the significant parameters have the expected sign. Focusing on results from the model (1) in Table 3, both block size and built area are highly statistically significant, with a 10 per cent increase in each increasing property prices by 2.2 and 2.4 per cent, respectively; recall the estimated coefficients on these variables are elasticities as we use the logarithms of these variables.¹⁷ The number of bedrooms has a positive and statistically significant impact on house price.

Table 4. Estimates of noise contour models and distance to the runway model controlling for neighbourhood dynamics. These models replace the quarterly time indicators with 15 year indicators (1999–2013, 1998 omitted category) that are interacted with suburb indicators. Models (1) and (2) correspond to models (1) and (2) from Table 2 and model (3) corresponds to model (1) from Table 3.

Variables	(1)	(2)	(3)
ANEF (25–30 omitted)			
20–25	0.060 (0.037)	0.043 (0.042)	
Outside 20	0.016 (0.040)	0.020 (0.044)	
ANEF 20–25 × after 2008		0.080 (0.066)	
Outside 20 × after 2008		–0.002 (0.055)	
Distance to runway			0.547*** (0.153)
(Distance to runway) ²			–0.161*** (0.054)
Annual time-fixed effects	Yes	Yes	Yes
Observations (<i>N</i>)	1,230	1,230	1,230
<i>R</i> ²	0.696	0.697	0.698

Note: *** denotes 1 per cent level of significance.

Table 5. Results from re-estimation of noise contour models (1) and (2) from Table 2 for the subsample period from quarter one of 2008 through to quarter four of 2009.

Variables	(1)	(2)
ANEF (25–30 omitted)		
20–25	0.129 (0.086)	0.108 (0.110)
Outside 20	0.029 (0.087)	0.044 (0.120)
ANEF 20–25 × after 2008		0.085 (0.162)
Outside 20 × after 2008		–0.020 (0.168)
Quarterly time-fixed effects	Yes	Yes
Observations (<i>N</i>)	196	196
<i>R</i> ²	0.561	0.563

Proximity to the freeway does not have a statistically significant negative impact on house value though the sign of the coefficient is consistent with expectations.¹⁸ The relationship between house price and distance to the nearest train station follows a second-order polynomial (jointly significant at $P = 0.006$ based on an F -test) with house prices increasing with distance to the nearest station up to 1.69 km, thereafter decreasing in value with this distance.

4.2 Robustness

We undertake a number of checks to test the robustness of these results. The first relates to the impact of neighbourhood dynamics on house prices, we interact time-fixed effects with our suburb indicators. For time-fixed effects, we adopt a more parsimonious series of 16 annual time indicators (1998–2013 inclusive with 1998 as the omitted category). We

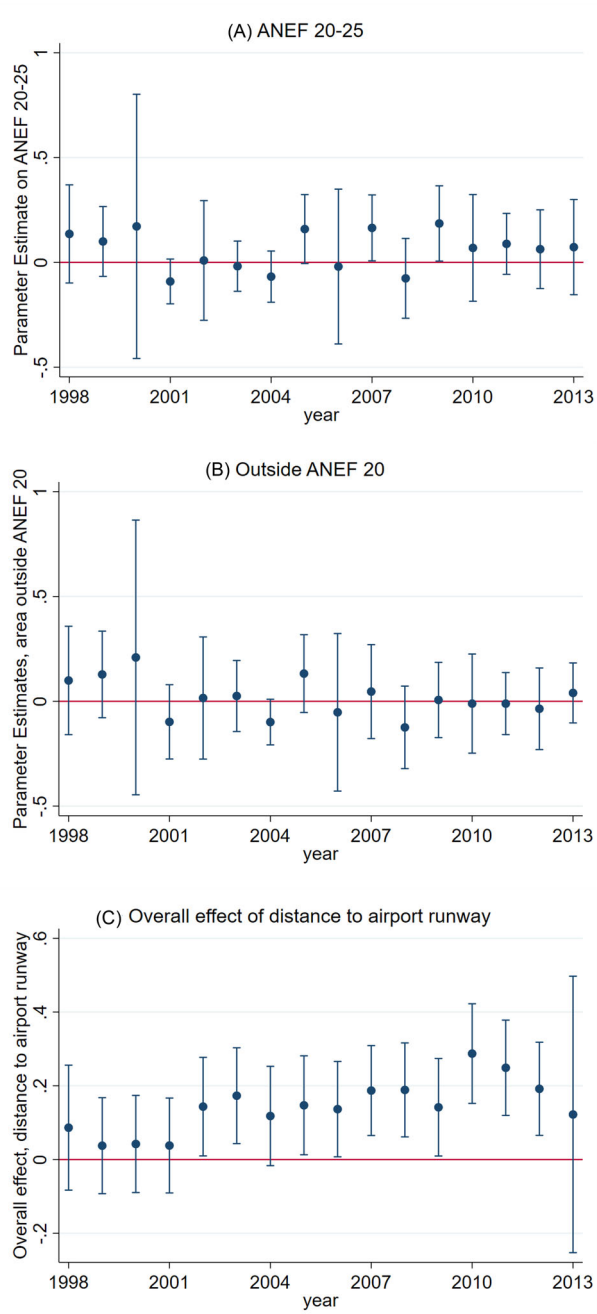


Figure 4. Estimated effects and 95 per cent confidence intervals of noise contours and distance to airport runway over time. Based on model (1) from Table 2 and Table 3 with quarterly time-fixed effects replaced with annual time-fixed effects and interacted with noise contours and distance to runway in respective models.

re-estimate models (1) and (2) from Table 2 and model (1) from Table 3 with the results presented as models (1)–(3), respectively in Table 4. The table shows the earlier results are qualitatively unchanged by the allowance for local dynamic effects in house prices.

The effects of the release of noise contour maps may be difficult to identify given the long period over which the models incorporating noise contours are estimated and the potential for amenity values to change over time (Kuminoff, Parmeter, and Pope, 2010). Our first strategy to deal with this is to re-estimate model specifications (1) and (2) from Table 2 for a shorter window from the first quarter of 2008 to the last quarter of 2009, focusing on the year before and after the release of the 2008 master plan. This minimises any possible time variation in amenity values, albeit at the cost of a smaller sample, providing a greater opportunity for the price effects of any new information in the master plan to be identified in the models.¹⁹ The parameter estimates for the noise contour variables are presented in Table 5. Results on the noise contours are qualitatively unchanged with the difference in difference parameter estimates on ‘ANEF 20–25 × After 2008’ and ‘outside 20 × After 2008’ in the model (2) both insignificant, maintaining the result that the release of the contour map did not change the price differences between noise contour areas.

Our second strategy to deal with possible dynamics in the effects of airport noise is to estimate model (1) from Table 2 and Table 3 with the noise contours and distance to the runway interacted with the time indicators (Zheng, Peng, and Hu, 2020). We again adopt a more parsimonious series of 16 annual time indicators (1998–2013 inclusive with 1998 as the omitted category). Estimates over time with 95 per cent confidence intervals are plotted in Figure 4, with panel (a) presenting parameter estimates on the ANEF 20–25 indicator and panel (b) presenting parameter estimates on the outside ANEF 20 indicator, both suggesting little evolution over time in the noise contour effects with results in models (1) and (2) from Table 2 robust to the interaction between noise contours and time indicators. Panel (c) of Figure 4 presents the overall effects of distance to the runway over time. The results suggest stronger effects later in the sample period with some evidence that distance becomes more important after the release of noise contour maps, though the results are relatively imprecisely estimated, possibly due to the small number of observations in each year.

5 Conclusion

We have shown that sale prices of homes near Essendon Airport in Melbourne, Australia, do not reflect the information in maps of ANEF contours. Instead, house prices are strongly correlated with the straight line distance of the property from the airport runway and annual aircraft movements. The distance relationship is nonlinear with the premium ranging up to 37 per cent for houses with identical observed characteristics that are 1.64 km from the runway, while the marginal effect of a 1000 flight reduction (average flights = 62,000) in annual aircraft movements is 4.5 per cent. While house prices are uncorrelated with ANEF contours, many of the houses this distance from the runway are located outside the ANEF 20 contour. However, many houses outside the ANEF 20 contour are closer to the runway than 1.64 km, some within 0.50 km of the runway. According to noise contour maps, these houses should be unaffected by noise from Essendon Airport and should not sell at the 15 per cent discount to those 1.64 km from the runway that they do. We undertook a number of robustness tests with results qualitatively unchanged. Aircraft movements were also found to have an important influence on house prices around Essendon Airport but the noise contour and distance effects are robust to the inclusion of aircraft movements.

These results imply that homebuyers seem to favour straight line distance as a measure of any potential disamenity arising from the nearby airport. This may be because homebuyers focus on distance as a proxy for a wide range of possible externalities from the nearby airport. Given the large literature that identifies the negative relationship between airport noise exposure and house price, we are reluctant to interpret the finding as evidence that

homebuyers are unconcerned by airport noise. It is more likely that homebuyers are using distance as a rule of thumb to approximate the noise and other effects of the nearby airport.

This latter explanation has important policy implications for the increasing push to better inform consumers. Noise contour maps of areas surrounding airports provide specialised information highly relevant to a range of stakeholders. However, in the market studied here homebuyers may be opting for a simpler more intuitive measure in distance from the runway. While contour maps meet regulatory requirements, these publicly available maps may not be easily understood by the general public or potential homebuyers may not be aware of their availability or how to access them. Regulators and governments wishing to provide information need to make it easily accessible and simple to understand; see [Bts.gov \(2017\)](#) for an example of such efforts in the USA. In the case of airports, a possible solution is to require affected home owners or their real estate agents, or both, to provide contour maps to potential buyers of houses near airports. However, improving access to such information is likely to lead to a redistribution of wealth and may be resisted by affected property owners.

Supplementary material

Supplementary data are available at [QOpen](#) online.

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Data availability

The data used in this paper were provided under a confidentiality agreement by the office of the Valuer-General Victoria. The data cannot be made publicly available.

End Notes

1. The then Minister for Infrastructure, Transport, Regional Development and Local Government announced the approval of the 2008 Master Plan with a ministerial media release in October 2008. There was no regulatory requirement that the master plan or maps therein be disclosed to homebuyers.
2. See [Baumol and Oates \(1988, Chapter 3\)](#) for a discussion of the impacts of externalities and [Cigdem-Bayram and Prentice \(2019\)](#) for a recent study of the impact of externalities arising from crime on house prices in Victoria, Australia.
3. [Theebe \(2004\)](#) provides a comprehensive study of the impact of traffic noise, including air traffic, for the Netherlands.
4. Melbourne Airport is also commonly referred to as Tullamarine Airport after the suburb in which it is located.
5. These movements include multiple types of aircraft. However, due to regulatory weight limits imposed on the airport, much of the aircraft activity is in the form of smaller planes and helicopters rather than large jets.
6. While we anticipate results to be robust to the inclusion of areas to the east, west, and north of Essendon Airport, it should be recognized that the results focus on the area to the south of the airport.
7. For more details of the development and introduction of the ANEF, see [Hede and Bullen \(1982\)](#) and the Commonwealth of Australia, Air Navigation (Aircraft Noise) Regulations 1984.

8. Noise levels are implied to be less than 35 ANEF units due to the absence of higher contours on the 2008 ANEF map.
9. Properties that formed part of multiple dwelling buildings like flats and townhouses are included in the analysis when the block size is available for these properties. Omitting block size and including properties for which this information is not available, such as apartments, leaves the results qualitatively unchanged but we opt to include block size as land costs are an important part of house price determination.
10. Five properties in our sample had six or more bedrooms. These cases were grouped together into a category referred to as six or more bedrooms.
11. There were a number of school closures and mergers in Victoria in the early 1990s but over the period of this study (1998–2013), public schools in the area of interest were unchanged.
12. See Rosen (1974) for a foundational reference on hedonic price models.
13. Census data on median incomes and the proportion of overseas-born immigrants for each suburb were considered but we opted for suburb indicators to control for any unobservable suburb-based variation in prices.
14. A log-linear specification of airport access and distance to the nearest train station was considered for models (1)–(4) in Table 2 but rejected (with a P -value of 0.017 or lower) in favour of a second-order polynomial based on a likelihood ratio (LR) test for each model. Similarly, a third-order polynomial was considered but the restriction to a second-order specification could not be rejected based on a LR test for models (1)–(4) with the lowest P -value of 0.245. A log-log specification for airport access and distance to the nearest train station was considered but rejected with a non-nested model comparison based on the Akaike Information Criterion (AIC).
15. While uncommon, on 21 February 2017, a light aircraft departing Essendon Airport crashed into a nearby shopping centre; see Australian Transport Safety Bureau (2017) for more details.
16. A log-linear specification of distance to the runway, airport access and distance to the nearest train station was considered for models (1)–(3) in Table 3 but rejected (with a P -value of 0.001 or lower) in favour of a second-order polynomial based on a LR test for each model. Similarly, a third-order polynomial was considered but the restriction to a second-order specification could not be rejected based on a LR test for these models with the lowest P -value of 0.702. A log-log specification for distance to the runway, airport access and distance to the nearest train station was considered but rejected with a non-nested model comparison based on the Akaike Information Criterion (AIC); for analysis and discussion of flexible specifications of hedonic models see Kuminoff, Parmeter, and Pope (2010).
17. As a robustness check, we re-estimate the models in Table 2 and Table 3 replacing the $\log(\text{block size})$ and $\log(\text{built area})$ variables with second-order polynomials of each respective variable; see for example Efthymiou and Antoniou (2013) and Schipper, Nijkamp and Rietveld (1998). The results are qualitatively unchanged.
18. It is possible that being located close to the freeway could have a positive impact on house value by improving access to other areas of the city. The travel distance to the closest freeway entrance for each property was calculated and included, as a second-order polynomial, in all models presented in both Table 2 and Table 3. This distance was not statistically significant, nor did its inclusion qualitatively change the results. Further, as the freeway was constructed between 1996 and 2000, we re-estimate the models in Table 2 and Table 3 using a sample period of 2001–2013 to avoid any effects of major freeway upgrades completed in 2000. All results are qualitatively unchanged.
19. Importantly, we do not re-estimate models (3) and (4) from Table 2 which include annual aircraft movements for this shorter 2-year window as there is insufficient variation in movements to identify the impact on house prices.

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