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The Influence of Aircraft Noise on the Prices of Residential Properties on the Example of Poznań

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Abstract: The article analyses the influence of aircraft noise on the transaction prices of residential premises within the Poznań property market. The paper analyses the set of properties, subject to the transaction from the first to the fourth quarter of 2020. In total, 1550 properties were examined. The study defined basic attributes of all premises, exhibiting the most significant influence on their price. The research conducted using the hedonic regression allowed for the identification of crucial evidence that aircraft noise negatively affects the property transaction prices.

Keywords: aircraft noise, property prices, hedonic methods

1. Introduction

Noise generated by aviation, as well as any additional, ancillary activities, constitutes an important issue, particularly for market participants, potentially interested in purchasing premises in the vicinity of the airport (Bishop & Laing 2020). It should be noted that, over the past years, as a result of substantial, technological progress, the noise from a single aircraft has been significantly reduced (Zellmann et al. 2019). Activities aimed at reducing noise emissions occur, among others, in connection with the implementation of the principles of sustainable development, which nowadays rise in importance (Dube & Nhamo 2020). However, it should be emphasised that, over the last years, along with the reduction of noise emitted from a single aircraft to the environment, air transport has been gaining in importance (Zhang & Graham 2020). As a consequence, despite the technological progress, the absolute value of noise emitted

to the environment from aviation activities has not decreased. In places particularly exposed to noise, it is extremely important to conduct activities involving the local spatial structure, aimed at reducing the negative impact of noise, generated by the transport industry (Podawca & Staniszewski 2019).

Air transport is considered to be the safest means of travelling, fulfilling the fundamental demands of sustainable transport and enabling fast and accessible for everyone movement between distant countries and continents (Bobrova & Stepanov 2019). Regardless of the presented, indisputable advantages of this form of transport, it also generates many crucial, economic and social costs. The most significant costs of such transport are borne by the residents of properties, located in the vicinity of large, international airports, as well as smaller, local ones. An increased number of flights, combined with their duration, directly affect the amount of noise emitted, which, in turn, results in a significant deterioration in the living conditions of the owners of properties adjacent to the airport (Eves & Blake 2016). It is important to examine the consequences of the airport's proximity on people residing in the area of its impact.

This paper aims to examine the impact of aircraft noise on the value of properties. The property market is unique, while the premises are considered to be specific goods, characterised by several individual features, including economic, legal, environmental and institutional ones. The property value, depending on its type, is influenced by its direct features (technical condition of the building, the parcel's size, finishing standard, etc.) and attributes considering the condition of the property's immediate surroundings, i.e. the quality of recreational areas, air pollution, vicinity of troublesome industrial facilities, etc. (Radzewicz & Wiśniewski 2012). The proximity of airports is also placed among the most important, indirect factors (Batóg et al. 2019). Complete analyses determining the impact of significant factors on the property value should involve factors from both the first and the second group.

2. Literature review

The activity of airports generates a number of social and economic consequences. Noise emitted from the airport's operation constitutes one of the most significant social costs, which directly affects residents of the impact zone. One of the available methods for examining the magnitude of the said costs consists in the analysis of changes in the value of properties located in the vicinity of the airport. Most frequently, such an impact is determined based on the preferences of the property market's participants, including transactional data concerning previous sales. The analyses usually apply models of hedonic price or multiple regression (Trojanek et al. 2017, Winke 2017, Thanos et al. 2012).

To analyse the impact of excessive exposure to noise on the property, the study employed the NDI (Noise Depreciation Index), defined as

a depreciation/amortisation index or the NSDI (Noise Sensitivity Depreciation Index), understood as an index of sensitivity to the decreasing values. The basic objective of both these indicators is to determine how the price of the property is affected by a 1dB change in the noise level. The subject literature, assessing the impact of noise on the value of properties has been previously analysed (Nelson 2004, Schipper et al. 1998, Bateman et al. 2001, Wadud 2013, Trojanek et al. 2017, Kopsch 2016) (Table 1).

Table 1. A summary of literature reviews conducted in relation to the NDI

Author/ authors	NDI	Study period	Area of the study	Scope of the study
Nelson	0.28-1.49%	1969-1993	USA, Canada	23 airports
Schipper et al.	0.1-3.57%	1967-1996	USA, Canada, Australia, UK	19 airports
Bateman et al.	0.29-2.3%	1960-1996	USA, UK, Canada, Australia	30 reviews
Wadud	0-2.3%	1970-2007	USA, Canada, Australia, UK, Netherlands, France, Switzerland, Norway	65 reviews
Trojanek et al.	-0.8-2.12%	1995-2014	China, Switzerland, Netherlands, Germany, Greece, Poland, Thailand, France	14 reviews
Kopsch	0.13-2.3%	1960-2009	Australia, UK, USA, Germany, Thailand, Netherlands, Canada, Switzerland	44 reviews

The presented NDI values reach different levels for various countries and individual airport examples. Therefore, it can be concluded that the prices of premises react differently to the proximity of the airport, which may be directly related to one of the main characteristics of the property market – its local character. The size and manner of impact may be furthermore associated with the scale of the airport, the spatial structure of existing buildings, different forms of noise measurement and the economic development of the country (Wadud 2013).

Analysing some of the recent studies regarding the impact of noise on the prices of properties located in the vicinity of airports, it can be noticed, that the majority confirms the negative influence of airport proximity on the said values (Chalermpong & Klaiklueng 2012, Püschel & Evangelinos 2012, Nguy et al. 2014). The exceptions are two studies (Huderek-Glapska & Trojanek 2013, Trojanek 2014) including the case of the Warsaw airport, in which, contrary to other studies, apartments and houses located closer to the airport were evaluated higher. Within the analysed studies, the obtained NDI values reached between -0.8 and 2.12% per 1 dB. It should be noted that a direct comparison of indicators received for the purposes of those studies may be misplaced, due to disparities in the type of the analysed properties, different methods of noise measurement, as well as various sources of data.

3. Area and material of the study

3.1. Area of the study

Poznań, located in the central-western part of Poland, constitutes the central part, as well as the capital of the Wielkopolskie Voivodship. According to the Statistics Poland, the city is inhabited by 533,830 residents (as of August 2020). The city area amounts to 261.9 km^2.

Fig. 1. The location of airports in Poznań. Source: own study

There are two airports in Poznań: Poznań–Ławica Henryk Wieniawski Airport (in the western part of the city) and the 31st Air Base, known as the Poznań-Krzesiny Airport (in the southern part of the city), owned by the National Air Force Command (Fig. 1).

Poznań-Ławica Henryk Wieniawski Airport was opened in 1945. The total area of the airport amounts to 310 ha, while its capacity reaches 3 million (the airport is capable of providing service to 3 million passengers each year). In 2019, the airport held a total of 31,923 air operations (Fig. 2A), within which, 2,379,635 passengers took advantage of flights (Fig. 2B).

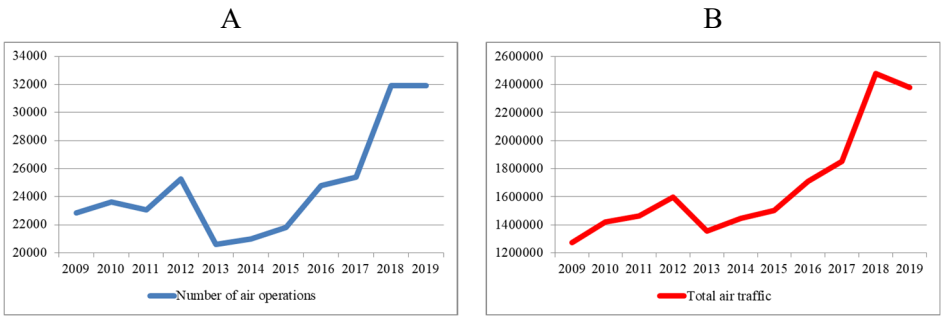

Fig. 2. The number of air operations at Poznań-Ławica Airport in 2009-2019 (A), total air traffic at Poznań-Ławica Airport in 2009-2019 (B)

Poznań-Krzesiny Airport is located within the are of the Military Unit No. 1156. The 31st Tactical Air Base is located in the same area, approximately 8 km from the city centre. Data obtained from the Environmental Noise Protection Programme for the City of Poznan in 2018 indicate that, in 2016, the total number of air operations occurring at the military airport increased by 12.5%, compared to 2011.

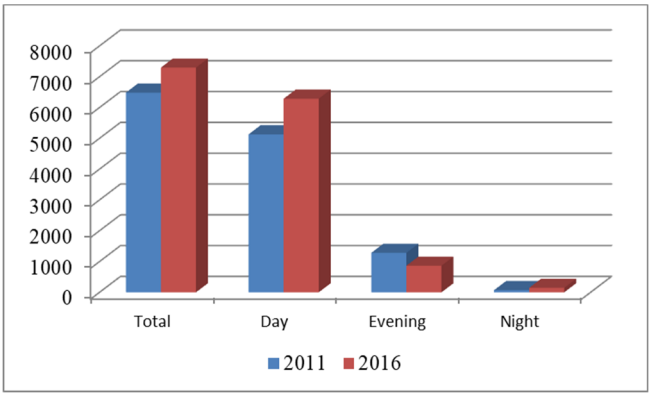

Fig. 3. The number of air operations at Poznań-Krzesiny Airport in 2011 and 2016

3.2. Study material

The following study is based on two groups of source data. The first, basic group, consists of data obtained from the Board of Geodesy and Town Cadastre "GEOPOZ" in Poznań, on the residential property transactions concluded in the city in 2020. The framework of this study does not involve property transactions, concluded in particular conditions, i.e. in non-market conditions, such as sale with a delayed date of release of the property to the buyer, or in the event of a bailiff's auction.

Transactional data obtained from the Board of Geodesy and Town Cadastre in Poznań were based on notarial deeds. The basic information collected in this database includes data on the transaction date and price, surface area (of the apartment), area of auxiliary premises, as well as information regarding the floor on which the dwelling is located. An attempt to determine factors that significantly affect the value of a property on the sole basis of data from such a register cannot be considered an acceptable approach, due to the unique nature of the property, according to which, its value is influenced by several attributes, undefined in the said register. To eliminate the problem related to the absence of complementarity data, additional information about the analysed properties, including the nearest neighbourhood and detailed location, was obtained.

The second group of source data consists of the information derived from the noise map of Poznań from 2017, related to aircraft noise occurring within the areas of restricted use of the Poznań-Ławica Airport and the Poznań-Krzesiny Airport.

The restricted use area of the Poznań-Ławica Airport constitutes an envelope of noise isolines with specified acceptable values, indicated separately for daytime and nighttime. The external zone is limited by: from the outside – a balanced sound level isoline of LAeq = 55dB for daytime and LAeq = 45 dB for nighttime (for noise generated by an aircraft landing, take-off and flight). In the case of noise from other aviation-related sources, the isolines assume the levels of LAeq = 50 dB (daytime) and LAeq = 40 dB (nighttime). From the inside, however, the zone is limited by a line constituting the envelope of the inner region of the restricted use area.

The internal zone of the area is limited by: from the outside – a balanced sound level isoline of LAeq = 60 dB for daytime and LAeq = 50 dB for nighttime (for noise generated by an aircraft landing, take-off and flight). In the case of noise from other sources related to aviation activities, the isolines assume the levels of LAeq = 55 dB (daytime) and LAeq = 45 dB (nighttime). A line running along the border of the airport area limits the zone from the inside.

The restricted use area of the Poznań-Krzesiny military airport is divided into three zones. Each zone strictly defines requirements on, among other aspects, the purpose of the land, the manner in which the land is used and tech-

nical requirements for constructions. Zone I is located in the area of Poznań, as well as the municipalities of Luboń, Komorniki and Kórnik. Zone II covers the city of Poznań, as well as the municipalities of Luboń, Kórnik, Mosina and Komorniki. Zone III involves the largest area, including Poznań, as well as municipalities of Luboń, Komorniki, Puszczykowo, Stęszew, Mosina, Kórnik, Kleszczewo and Środa Wielkopolska.

4. Research methodology

The method of statistical analysis has marginal importance in the process of property valuation. In everyday practice, the valuers employ it in an extremely limited extent. On the other hand, however, analyses of the property market based on mathematical statistics find many applications, as well as enable reliable and effective market characterisation established on unambiguous indicators. The most frequently applied methods based on statistical analysis include models, such as hedonic, regression, spatial analysis and artificial neural networks (Trojanek et al. 2017).

In the property market analyses, hedonic methods have been successfully used since the 20th century (Rosen 1974). The basic aim of such models consists in answering the question of how the analysed, specified factors influence the property value. The main idea of hedonic models involves the assumption that the price of a certain good (in this case – a property), is characterised by several selected attributes. As a result, the hedonic model allows determining the value of the analysed features, as elements of the whole, i.e. the property price. The assumed property characteristics, such as the level of aircraft noise or location, constitute the explanatory variables. The property price will result directly from the selected explanatory variables.

$$C = \beta_0 + \sum_{i=1}^{K} \beta_i X_i + u \tag{1}$$

where:
C – property price,
β – regression coefficient,
X – the value of the analysed attribute,
u – random error.

In the analyses of the property market using the hedonic models, the most commonly applied is the regression function, based on the natural logarithm, resulting from the possibility of changing the value of a certain feature proportionally to the changes of others. However, in the case of linear models, it is possible only to determine the influence of the selected feature's improvement (e.g. the finishing standard for all properties in the analysed set), without specifying the impact of the improvement in the standard of apartments with, for

instance, different surface areas. Further advantages of the logarithmic function consist in straightforward interpreting of coefficients, as well as eliminating the problem of random element variability (Trojanek 2014). Therefore, the following study is also based on a logarithmic model.

Moreover, the key issue consists in the selection of features that most significantly affect the property price. One of the basic functions of properties is their diversity, which entails, among other things, that attributes affecting the value of a given type of property are not necessarily relevant for premises of different types. In the case of residential properties, the most important features appear to involve location, neighbourhood, form of ownership, upper-floor location and surface area (Radzewicz & Wiśniewski 2012). The following study analyses an additional feature, defined in the property price – the level of noise emitted from air transport. Considering the above-mentioned assumptions, the hedonic function of the price may be presented in the following manner:

$$\ln(C) = f(\text{location, neighbourhood, the form of ownership, upper-floor location, surface area, aircraft noise}) \quad (2)$$

5. Results

To determine the impact of aircraft noise – imposed by the location of the property in the restricted use zone – on apartment prices, the paper collected information on the transactions of residential premises within the city of Poznań, from the first to the fourth quarter of 2020. The data were initially used to conduct a preliminary analysis of correlations between aircraft noise and the property market in 2020 in Poznań.

The analysis shows that only two transactions originate from the area located in the airport's immediate vicinity, namely the premises in Jeżyce, which are partly situated in the zone of the restricted use of the Poznań-Ławica Airport. A total of 168 transactions were recorded in the zones of limited external use in both Poznań-Ławica and Poznań-Krzesiny airports, the highest number of which occurred in Grunwald (57) and Jeżyce (41). Outside the restricted use zones of both airports, the study collected data on 1380 residential unit transactions, mainly from districts of Rataje (161), Nowe Miasto and Winogrady (145). In total, data on 1550 transactions were recorded, while the vast majority involved premises located outside the restricted zones (Table 2).

Table 2. The number of offers regarding residential units in each district of Poznań

District	Inside the zone		Outside the zone	Total
	Zone I	Zones II and III		
Central Poznań	0	0	111	111
Górczyn	0	35	86	121
Grunwald	0	57	80	137
Jeżyce	2	39	79	120
Łazarz	0	29	84	113
Nowe Miasto	0	0	145	145
Piątkowo	0	0	130	130
Rataje	0	0	161	161
Sołacz	0	8	55	63
Stare Miasto	0	0	109	109
Wilda	0	0	109	109
Winiary	0	0	86	86
Winogrady	0	0	145	145
Total	2	168	1380	1550

To initially verify the impact of aircraft noise on the transaction price, a median of prices was determined in districts, where the offers occurred within the restricted use zone (Table 3).

Table 3. The median of offer prices inside and outside the restricted use zone, including the districts of Poznań

District	Inside the zone	Outside the zone	The median difference (%)
Górczyn	6954	7679	-9.44
Grunwald	6242	6990	-10.70
Jeżyce	6298	7400	-14.89
Łazarz	5882	6990	-15.85
Sołacz	7950	8789	-9.55

In each of the analysed districts, the median of property transactional prices is lower among those located in the restricted use zone, compared to those located outside the zones. However, based on the median of prices, one cannot derive any significant conclusions about the influence of the analysed factors on the property price, as it does not include the most important features that significantly determine the price.

A multi-factor analysis of the price function was applied in order to include several analysed factors affecting the property price. With regard to property prices, the most frequently used is the hedonic method. Therefore, to determine the impact of the restricted use zone on property prices, the hedonic regression was conducted. The selection of variables applied in the model resulted, among others, from the availability of data. The study used the following variables: location, neighbourhood, the form of ownership, upper-floor location, surface area and aircraft noise (Table 4).

Table 4. The values of qualitative and quantitative variables applied in the model

Variable	Symbol	Characteristics of the feature
Location (district)	d_1 – Poznań Centrum, d_2 – Górczyn, d_3 – Grunwald, d_4 – Jeżyce, d_5 – Łazarz, d_6 – Nowe Miasto, d_7 – Piątkowo, d_8 – Rataje, d_9 – Sołacz, d_{10} – Stare Miasto, d_{11} – Wilda, d_{12} – Winiary, d_{13} – Winogrady	13 variables were assumed – if the property is located in a given district, it adopts the value of 1. For the remaining variables, the value amounts to 0.
Neighbourhood	s_1 – neighbourhood	One variable was assumed. If the apartment is located in a well-developed neighbourhood, it receives the value of 1. Otherwise, the value amounts to 0.
Form of ownership	w – ownership	If the apartment is the subject of ownership, it receives the value of 1. Otherwise, the value amounts to 0.

Table 4. cont.

Variable	Symbol	Characteristics of the feature
Upper-floor location	pp – upper-floor location	The variable assumes the value of 1 for a location on the first, or higher floors if the building has an elevator. Otherwise, the value amounts to 0.
Surface area	pow – useful floor area	Useful floor area measured in square meters.
Aircraft noise	hl – restricted use zone	Two variables of the feature were adopted. If the property is located in an area where aircraft noise exceeds 55 dB, it receives the value of 1. Otherwise, the value amounts to 0.

In the following stage, appropriate function parameters were estimated with the use of RStudio software. Both the property price included in the model, as well as the analysed attributes, were explanatory variables.

Table 5. Estimation of function parameters, dependent variable – price

	Coefficient	Standard error	T-value	P-value
constant	8.92497	0.08937	99.863	< 2.00E-16
d_1	-0.05911	0.03150	-1.877	0.06075
d_2	0.06738	0.03137	2.148	0.03189
d_3	-0.06613	0.03165	-2.089	0.03683
d_4	-0.02831	0.03195	-0.886	0.37577
d_5	-0.09761	0.03234	-3.018	0.00259
d_6	-0.07252	0.02965	-2.446	0.01455
d_7	-0.00577	0.03161	-0.183	0.85518
d_8	-0.09141	0.02849	-3.209	0.00136
d_9	0.17095	0.03890	4.394	1.19E-05
d_{10}	0.10581	0.03136	3.374	0.00076
d_{11}	-0.02647	0.03139	-0.843	0.39914
d_{12}	0.14069	0.03395	4.144	3.61E-05

Table 5. cont.

	Coefficient	Standard error	T-value	P-value
constant	8.92497	0.08937	99.863	< 2.00E-16
S1	0.08404	0.01501	5.598	2.56E-08
w	0.06381	0.02035	3.136	0.00175
pp	0.12829	0.01497	8.571	<2.00E-16
pow	-0.05606	0.02107	-2.661	0.00788
hl	-0.04578	0.02401	-1.907	0.05668

The analyses conducted on the basis of collected data did not allow for the identification of one of the coefficients for variable d_{13}, due to its absent differentiation. The difference between the observed values and the dependent variable defined by the standard error amounted to 0.2468, with 1528 degrees of freedom.

Based on the conducted analyses, it can be observed that in the examines period (2020), the residential property prices were significantly affected by their location in specified districts of Poznań. Location in the districts of Sołacz, Stare Miasto and Winiary was particularly important for the increase in prices. Moreover, while analysing the results, one can undeniably state that the price was significantly influenced by its closest neighbourhood and upper-floor location (Table 5).

Moving to the main purpose of this paper, the explanatory variable related to aircraft noise is statistically significant. The application of the hedonic regression based on the natural logarithm allowed for the identification of the percentage change in the difference of property prices with comparable characteristics, located in the area exposed to noise above 55 dB, as well as below this value. The coefficient of the feature (hl) assumed the value of -0.04578 (Table 5), which indicates that premises exposed to aircraft noise on average, adopt a value lower than 4.58%, compared to properties located outside the impact zone of the airport.

6. Discussion of the results

The study conducted within the framework of this paper constitutes one of the first studies related to the analysis of the impact of aircraft noise on the value of the residential properties in Poland. The vast majority of available studies involve the analysis of the impact of airport proximity, primarily in the United States (Cohen & Coughlin 2009, McMillen 2004), Western European countries (Püschel & Evangelinos 2012, Le Boennec & Salladarré 2017) and Canada (Maguire & El-Geneidy 2018).

A direct comparison of the obtained results with the previous studies may be restricted due to the differences in the location of the airport or the conditions of the local property market. The fact that the analysis covered a specific type of property should be taken into consideration as well. Taking into account the study (Trojanek et al. 2017) presenting the correlations between aircraft noise and prices of different types of properties within a single market, it should be emphasised, that the impact of this feature may vary. As a consequence, the obtained results and conclusions formulated on their basis, apply solely to the residential properties.

However, referencing to the existing studies which summarise the previous research on the impact of aircraft noise on the property value (Wadud 2013, Kopsch 2016, Batóg & Foryś & Konowalczuk 2019), one can notice a certain similarity between the results obtained in this study and the literature on the subject. The conducted analyses allowed for the identification of a statistically significant, negative impact of the airport's proximity on the property value, similarly to recent studies (Zheng et al. 2020, Bełej et al. 2020, Cellmer et al. 2019).

The analysis was performed according to the modified methodology, relating to the previous analyses (Huderek-Glapska & Trojanek 2013, Trojanek et al. 2017). Within the framework of this study, the variable related to aircraft noise was defined by two variables. As a result of preliminary analyses, it was possible to identify that, due to the criteria by which the existing restricted use zones in both local airports are designated, the ones located in areas where the value of aircraft noise exceeds 55 dB are particularly exposed to noise. In connection with the adopted criteria, we have determined how the location in the area in which the value exceeds 55 dB affects the transaction prices.

The analyses were conducted based on the 2017 noise map of Poznań. The obtained results are properly justified, there are some certain limitations to the solution mainly resulting from the lack of data. In this situation, the problem may arise in connection with the validity of data, as the noise maps are prepared in a five-year perspective. Therefore, the analyses were performed in accordance with the available materials, which, however, are not necessarily consistent with the actual state of affairs during the research. It is necessary to consider the fact that the acoustic conditions in the city may change over time as a result of, among other things, the intensification of air traffic. The obtained results may not be valid in the following years, due to modifications in actual conditions. Moreover, the restrictions of the presented method may be related to the fact that the impact of proximity to airports in other regions/cities of Poland may be different as it depends on local conditions. Finally, it is worth noting that the research area covers several districts of Poznań, which means it doesn't take up much area. Consequently, it is difficult to draw universal conclusions that could

be formulated for other larger study sites. Monitoring of the impact of aircraft noise on the property market should be conducted in a continuous and systematised manner, which enables the observation of dependencies occurring over a longer period of time.

7. Conclusions

1. The application of a logarithmic model allows for determining the percentage difference in the transaction price of a residential unit, located within a zone particularly exposed to noise (55 dB), as well as outside that zone.
2. Within the local property market, aircraft noise constitutes a statistically significant attribute reducing the prices of premises.
3. Properties are considered to be special goods. Their price is influenced by several of factors, resulting directly from the local character of the property market.
4. The manner in which the selected attributes interact with one another may vary, depending on the type and spatial extent of the property market. The impact of relevant factors on price may also vary with time and local planning, social and economic conditions.

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