NEGATIVE EXTERNALITIES AND IMPLICIT NON-LINEAR PRICES: CAPITALIZATION OF HIGHWAY NOISE INTO HOUSING VALUES

(Tentative Title and First Draft)

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ABSTRACT

Conventional hedonic theory describes the implicit price of each housing attribute as non-linear and increasing with the amount consumed. Yet, few studies account for this price non-linearity. The current study exploits unique micro data and special acoustic equipment to estimate the impact of highway noise on housing prices. A prominent advantage of our study is the location and nature of the examined neighborhood, which provides a natural experiment for assessing the traffic noise externality. We observe the housing price and characteristics in an isolated neighborhood of newly constructed single family dwelling units located near the only highway to Haifa. The highway noise is the only observable or sound-related externality at the neighborhood's surroundings. Since all the units are newly constructed, housing prices reflect a direct capitalization of the traffic noise externality. We employ an acoustic device to measure the levels of highway noise at a radius of up to 800 feet from the highway, which covers all the dwelling units in the neighborhood. Unlike other studies, however, we use polynomial curve fitting, which permits non-linearity in the implicit price of 1 dB. Results indicate a high level of traffic-related noise near the highway (68.0 dB), and, compared with previous literature, higher and significant incremental price discount estimates of 0.953%-0.978% per each additional dB. Moreover, research findings suggest a significant increase in the incremental price discount per 1 dB with the level of noise from 0% at 50 dB to 4.83% at 55 dB.

Key Words: negative externalities, housing values, traffic noise.

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1. INTRODUCTION

Traffic air pollution and noise in large cities exert negative externalities on the public health system, which is financed by public funds. In their review study, Tetreault et. al. (2013) note the indirect effect of traffic noise on cardiovascular disease. The authors suggest that noise acts through stress responses from neural activation or cognitive interpretation, as well as disturbed sleep patterns. Similarly, overnight exposure to aircraft noise with a maximum noise level of 60 dB seems to impair the endothelial mechanism responsible for the expansions of blood vessels (Schmidt et. al., 2013).[1] Moreover, chronic exposure to traffic noise is associated with sleeping disorders, which, in turn, are responsible for an increased risk of breast cancer (Sorensen et. al., 2014).[2]

There is also a substantial body of empirical literature, demonstrating that traffic externalities including traffic noise is capitalized into housing prices. Hughes and Sirmans (1992) compared the housing prices in two sub-samples obtained from the multiple listing services in the Baton Rouge, Louisiana metropolitan area. They found that, holding everything else equal, housing prices are expected to drop significantly by 8.48% with high traffic volumes. Along similar lines, Larsen and Blair (2014) found that compared with detached single-family units located along non-arterial streets in Kettering, Ohio, the value of similar units located along arterial streets significantly drops by 7.8 per cent. Ossokina and Verweij (2015) examined the

[1] By exposing 18 respondents to traffic noise in the laboratory, Hemmingsen et. al. (2015) found oxidative stress and damage to the DNA.

[2] Referring to sleeping disorders, Bodin et. al. (2015) found a reduction in the level of reported sleeping annoyance in dwelling units with a quiet side than those having at least at least one window facing a yard, garden or green space. Another strand of the literature demonstrates a relationship between sleeping disorders and car accidents. See, for example, Philip et. al. (2010), Smolensky et. al. (2011), Williamson et. al. (2011), and Inoue and Komada (2014).

effect of reduction in traffic density emanating from the opening of a new bypass in The Hague, Holland. The authors found that a reduction of 50% in traffic density induces a 1.4% increase in housing prices

Referring specifically to direct measures of traffic noise, Nelson (1982) surveys nine hedonic studies, of which six are field studies, that make use of mobile acoustic equipment, and only three of them employ noise indices based on stationary acoustic equipment situated by the Ministry of Transportation at different locations. The stationary acoustic equipment is less suitable for hedonic methods that seek to distinguish between different levels of traffic noise based on spatial location in small regions, but is more suitable for repeated sales methods, which attempt to measure the effect of variation of noise levels across time on housing values.

Studies that came after Nelson (1982) include Palmquist (1982, 1992), and Wilhelmsson (2000). [3] Palmquist (1982, 1992) employed the empirical repeated-sales and hedonic models, respectively, and a noise monitoring system via measurement taken at 57 locations in a residential area north of Seattle, Washington to construct 2.5 dB contour lines for equal noise levels. His findings suggest 0.48%, 0.3% and 0.08% of anticipated price decrease per dB in upper middle-income, middle-income, lower-income and poor neighborhoods, respectively. Wilhelmsson (2000) extended the work of Palmquist by inclusion of two traffic noise variables. The first variable is the projected level of traffic noise for each dwelling unit, estimated via the Nordic Noise Model. The second variable is an interaction between the level of noise above 68 dBA and a dummy variable that equals 1 if the unit has a view of the

[3] Despite the fact that Israel has the highest traffic density level among OECD countries, very few studies in Israel have investigated the impact of traffic noise on housing prices. A noteworthy exception is Odish and Fleishman (2002), who estimated the traffic externality effect on condominium housing prices in three neighborhoods in Jerusalem. Their findings suggest that the anticipated housing price decline is 0.49% for each additional dB above 46 dB.

major road. His findings suggest an average noise discount of 0.6% per 1 dB in a suburb of Stockholm, Sweden,[4] or a total discount of 30% of a price for a house in a noisy location, compared with a quiet one.

The objective of the current study is twofold. The first aim is to exploit unique micro data and special acoustic equipment to estimate the impact of highway noise on housing prices. The second objective is to use polynomial curve fitting, which permits non-linearity in the implicit price of 1 dB; and its variation with different levels of noise. Conventional hedonic theory (e.g., Rosen, 1974; Nelson, 1982; Quigley, 1982; Follain and Jimenez, 1985) describes the implicit price of each housing attribute as non-linear and increasing with the amount consumed. Yet, few hedonic studies have accounted for this price non-linearity.

Compared with previous studies, there are two prominent advantages to our data set. The first advantage lies in the spatial location and nature of the examined neighborhood. We observe the housing price and characteristics of newly constructed detached single-family units in an isolated new neighborhood in the city of Atlit, Israel located near the only highway to Haifa, a metropolitan center about 10 miles to the north. The spatial location of this neighborhood near the highway, without any other observable or sound-related positive or negative externalities, enables better isolation of traffic noise effects.[5] The fact that all the units are newly constructed, and the externality is clearly observable or sounded to potential buyers, permits a direct

[4] According to Wilhelmsson (2000), dB is a noise measure that seeks to approximate the perception of the human ear. For the human ear, the noise generated by pick-up truck (70 dB) sounds twice as loud as the noise generated by an air conditioner (60 dB) and four times as much as the noise generated by a clothes dryer (50 dBA). The formula proposed by Nelson (1978) for the perceived loudness is 2^N, where N is the dB measure divided by 10.

[5] Atlit is located near the Mediterranean sea. However, there is no view to the sea from the surveyed dwelling units.

capitalization of the traffic externality into the units prices. Unlike Wilhelmsson (2000), a rampant located before the dwelling units, which are the closest to the highway, blocks the view of the highway, but is not very efficient in attenuating the traffic-noise-related nuisance.

The second advantage lies in the precise measurement of the level of traffic noise at a very small radius of only 836 feet (255 meters), which fully covers all the dwelling units of the neighborhood. We employ a mobile acoustic device to measure the levels of highway noise at six different spatial locations of the neighborhood. [6] Consequently, our study provides a much more subtle spatial measure of traffic noise levels among dwelling units located in close proximity to one another.

The first step of our analysis demonstrates the Doppler effect, namely, the drop in the level of traffic noise with distance from the highway. Based on noise measurements at six different locations, the maximum (minimum) level of noise is 68.0 dB (46.5 dB).[7] The respective distance from the highway in which the maximum (minimum) noise measurement was taken is 98.43 feet (836.61 feet). A simple regression analysis reveals a statistically significant drop of 4.59% or 2.545 dB for each additional 100 feet from the highway (significant at a 5% significance level).

Having demonstrated this drop in the level of traffic noise with distance, the next step focuses on measuring its impact on housing prices. Results indicate a significant incremental price drop of 0.953%-0.978% per each additional 1 dB. Interestingly,

[6] Unlike precise field measures at different locations, Bailey (1977) measured the distance of each unit from the highway up to 1,000 feet, and used the NPL scale to approximate the noise level in dB indirectly.

[7] Bodin et. al. (2015) surveyed 4,800 individuals sampled based on different traffic noise levels and received answers from 2,612 respondents living in Malmö, Sweden. They found that out of the total sample, 32% and 43% reported on sleeping annoyance due to road traffic noise in the 50-54 dB and 55-59 dB categories, respectively. This proportions rise to 50% for dwelling units without access to a quiet side, namely at least one window facing a yard, garden or green space.

even the lower bound of these estimates is above equivalent estimates obtained in Palmquist (1992), Wilhelmsson (2000), and Odish and Fleishman (2002) of 0.48%, 0.60% and 0.49% drop per each additional dB, respectively.

Finally, we provide clear evidence for the variation of incremental price discount with the level of noise. While for the 50 dB level - we cannot reject the null hypothesis that the housing price discount on the incremental 1 dB equals 0%, starting from the 51 dB level - this discount becomes negative and significantly different from 0% even at the 1% significance level. The incremental housing price discount steadily and significantly decreases (at the 5% significance level) with higher level of noise, until it reaches -4.83% and -4.55% for the maximal level of noise of 55 dB. These outcomes indicate that the linear model, which yields a fixed estimate of between -0.987% and -0.953%, may be mis-specified. While at the lower end of 50 dB and below, quiet seems to become a neutral and even an inferior good, with the rise of the noise level, quiet seems to become more and more superior good.[8]

Another aspect demonstrated by the analysis is the increase in the 95% confidence interval with the level of noise. For a 51 dB, the gap between the lower and upper bound of the 95% confidence interval is the smallest and is -1.09% and -1.04%, respectively. This gap steadily increases, until it reaches its peak at the noise level of 55 dB, where this gap is -6.93% and -7.96%, respectively. These outcomes imply that with the increase in the level of noise, the preferences referring to this negative externality become heterogeneous, and depend on subjective level of susceptibility to this negative externality.

[8] Our findings suggest that within the range of 47.0 dB-50.00 dB we cannot reject the null hypothesis that quiet is either an inferior, neutral or superior good, The former result that quiet is an inferior good is consistent with the interpretation that individuals dislike too much quiet.

The rest of this paper is organized as follows. Section 2 describes the neighborhood, where the research methodology was applied, and the acoustic measurements. Section 3 provides descriptive statistics. Section 4 exhibits the empirical model and reports the results. Finally, section 5 concludes and summarizes.

2. BACKGROUND

Atlit is a small town located south of Haifa, with approximately 6,560 inhabitants (Central Bureau of Statistics, 2014). The town is characterized by a majority of single-family detached units. The Israeli Tax Authority documents a total of 773 sales between 2001-2016, of which 224 were transactions of newly constructed single family units.

Figure 1 presents a map of the Nechalim neighborhood. Figure 2 displays variation of traffic noise with distance from the highway. The red dots P1, P2, P3, P4, P5, P6 in Figure 1 are the six points where readings of traffic noise were taken by the acoustic equipment, and P1 (P6) is the closest (most distant) site, to (from) the highway. Readings were taken at March 4, 2012 (starting from 17:22 PM); March 18, 2012 (starting from 6:41 AM); and March 22, 2012 (starting from 6:21 AM).

As Figures 1 and 2 demonstrate, the dwelling units in the neighborhood are located west to Highway 2 - the only direct highway that connects Tel Aviv to Haifa, the second and third most populated cities in Israel.[9] A visual inspection of the research site reveals two acoustical barriers, which separate the highway from the

[9] According to the 2014 Report Number 7 of the Central Bureau of Statistics, the most populated cities in Israel are: Jerusalem -850,000 persons; Tel Aviv - 414,600 persons; and Haifa - 277,200 persons, consisting of 10%, 4.9% and 3.3% of the total population in Israel, respectively).

first-row of dwelling units in the neighborhood.[10] The first barrier is a sand rampart located 100 feet from the highway. The measured level of noise at that distance (P1) is 68 dB - approximately the same level of noise generated by pick-up trucks (Wilhelmsson, 2000). The second barrier relates to the actual distance of 129 feet between the sand rampart and the first row of the single-family dwelling units located closest to the highway (P2). The switch from P1 to P2 reduces the noise level from 68 dB to 55.10 dB. Still, 55.10 dB - is a level of noise that generates sleeping annoyance.[11]

The dwelling units in the Nechalim neighborhood span points P2 (a measured noise level of 55.10 dB - 229.66 feet from the highway) and P6 (a measured noise level of 46.50 dB - 836.61 feet from the highway). A simple regression analysis between ln(dB) and the distance from the highway reveals a statistically significant drop of 4.59% or 2.545 dB per each additional 100 feet distance from the highway (significant at a 5% significance level). These findings exemplify the Doppler effect. If we consider the traffic in the highway as the steady sound source and the residents of the housing units as the receivers, as the receivers move closer to the sound source, the frequency of wave increases, so that the receiver will experience a louder noise.[12]

These outcomes and their compliance with the Doppler effect may demonstrate the reliability of measurements preformed in our study. Nelson (1982) points out that one of the problems associated with field studies is their coverage of a

[10] The visual inspection was carried out on Tuesday, August 16, 2016

[11] In a survey made by Bodin et. al. (2015), out of the total sample of 4,800 respondents, who live in dwelling units without access to a quiet side, 50% reported on sleeping annoyance due to road traffic noise above 50 dB.

[12] The formula, which captures the Doppler effect for a stationary sound source is $f = \left[\frac{c+v_r}{c}\right] f_0$, where f is the observed frequency, f_0 is the emitted frequency; c is the velocity of the wave in the medium; v_r is the velocity of the receiver, which receives positive values if the receiver is moving toward the source and negative values otherwise (see, for example, Rosen and Gothard, 2009).

short time period ranging from a few days to five minutes. To address this concern, our acoustic measurements were taken in the morning and at the evening hours. Nelson (1982) also points out that: "Distance measures, such as that used by Bailey, or dummy variables for noise levels are excellent alternatives to field surveys." (p. 126). This argument indicates, however, that traffic noise indices are based on stationary acoustic equipment, which provide no regional variance. Consequently, the technique we employ permits the combination of both distance measures with acoustical measures with mobile acoustical equipment. This, in turn, generates a regional variance of noise on a very small region of less than 1,000 feet.

3. DESCRIPTIVE STATISTICS

Table 1 reports the descriptive statistics of single-family newly constructed units. The upper (lower) part of the table refers to 224 sales in Atlit during 2001-2016 (of the 135 units included in Figure 1, 106 transactions at the Nechalim neighborhood during 2004-2012 - consisting of 78.5% of the total number of sales) With the exception of the dB measurements described above, all the sales-related information employed in this research information are extracted from the data-set of the Israeli Land Authority. We use the data obtained on Atlit transactions to construct a hedonic housing price index for Atlit - as a proxy for the housing market conditions.

As can be seen from Table 1 - the average non-deflated sales price of a unit in Atlit is $ 309,231 and in the Nechalim neighborhood - $ 328,766 (*PRICE*). As previously noted, the minimum (maximum) level of noise in the Nechalim neighborhood is 46.50 dB (55.10 dB), and the average noise level is 50.56 dB. The average year in which the units were sold is 2007 in Atlit and 2009 in the Nechalim neighborhood (*YEAR*). During 2001-2016, the housing price index rose by 44.19%, whereas during 2004-2016, the housing price index rose by 39.58% (*HPI*). The average area of each dwelling unit is approximately 1,590 square-feet, and in Nechalim neighborhood about 1,638 square-feet (*AREA*). Each dwelling unit contains on average 5 rooms (*ROOMS*) (not counting kitchen or bathrooms). Finally, note that the typical newly constructed housing unit in Atlit is low-rise. Most units are one-storey, with the maximum reaching three-stories (*FLOOR*S).

4. METHODOLOGY AND RESULTS

4a. The Empirical Model

To estimate the impact of highway noise on housing prices, we use the standard hedonic approach and extend the model proposed by Nelson (1982). According to Lancaster (1966) and Rosen (1974), housing units are considered to comprise bundles of different characteristics, including better environmental conditions, such as a lower level of traffic noise. From each of these components, the consumer receives pleasure.[13] Consequently, each component has an implicit price, which is revealed via regression analysis.

Nelson (1982) summarizes and reviews nine empirical studies, which estimate specifically the impact of traffic noise externality on housing values. He exhibits a simple structural hedonic model employed in these studies. Along similar lines, we specify the following model with two structural equations:

[13] According to McDonald and McMillen (2011), the term "hedonic approach" is derived from the pleasure the residential housing consumer receives from each housing and environmental component. Originally, the term "hedonic" implies pursuing of pleasure.

$$PRICE = b_0 A^{b_1} \exp(ZB_2 + u_1) \qquad (1)$$

$$A = c_0 \exp(c_1 L + u_2) \qquad (2)$$

where *PRICE* is the value of the housing price; A is the subjective annoyance due to traffic noise; *Z* is a matrix of market characteristics and physical characteristics of the unit ($Z = [HPI, YEARS, AREA, ROOMS]$, where *HPI* is the housing price index measured in percentage points; *YEAR* is the year in which the unit was sold; *AREA* is the unit's area measured in square feet; *ROOMS* is the number of rooms); L is an objective measure of traffic noise; b_0, b_1, c_0, c_1 are structural parameters; B_2 is a column vector of structural parameters; and u_1, u_2 are the stochastic random disturbance terms.

Equation (2) is motivated by acoustical studies, which show that the level of annoyance from traffic noise increases exponentially with the objective level of noise. In all field studies we are aware of the fact that the objective level of traffic noise (*L*) is measured in decibels as a function of distance from the highway (*dB(D)*) and is simply incorporated as a linear and proportional function of *L* (namely, *L*=*dB*). However, as Figure 2 indicates, our research environment exhibits a non-linear drop in the objective level of traffic noise with distance from the highway. Consequently, we approximate this non-linear drop by a polynomial function given by equation (3):

$$L = d_0 + d_1(dB) + d_2(dB)^2 + d_3(dB)^3 + d_4(dB)^4 \qquad (3)$$

where $(dB), (dB)^2, (dB)^3, (dB)^4$ is the level of noise measured in decibels and raised to the power of 1, 2, 3 and 4; and d_0, d_1, d_2, d_3, d_4 are parameters.

Substituting equations (3),(2) and $Z=[HPI, YEARS, AREA, ROOMS]$ into equation (1), and taking the natural logarithm from both sides, yields the reduced-form equation to be estimated:

$$\ln[PRICE]=\alpha_0+\alpha_1(dB)+\alpha_2(dB)^2+\alpha_3(dB)^3+\alpha_4(dB)^4$$
$$+\alpha_5 HPI+\alpha_6 YEAR+\alpha_7 AREA+\alpha_8 ROOMS+u_3 \qquad (4)$$

Where $\ln[PRICE]$ is the natural logarithm of the housing price; $\alpha_0,\alpha_1,\alpha_2,\alpha_3,\alpha_4,\alpha_5,\alpha_6,\alpha_7,\alpha_8$ are parameters and u_3 is the random disturbance term.

A major advantage of the reduced-form semi-logarithmic model is the direct interpretation of coefficients as percent of housing price discount for each incremental 1 dB. According to McDonald and McMillen, 2011 the use of semi-logarithmic instead of the linear hedonic model is widespread in hedonic studies. Compared with the linear model, the semi-logarithmic model usually fits the data better.[14]

Referring to the explanatory variables $(dB)^2,(dB)^3,(dB)^4$, unlike the simple linear model, the polynomial model specified by equation (4) permits the incremental housing price discount on each additional 1 dB to vary with the total level of noise measured in dB. Derivation of $\ln[PRICE]$ in equation (4) with respect to dB yields:

$$\frac{d\ln[PRICE]}{d(dB)}=\frac{d[PRICE]/[PRICE]}{d(dB)}=\alpha_1+2\alpha_2(dB)+3\alpha_3(dB)^2+4\alpha_4(dB)^3 \qquad (4a)$$

or

[14] We also run six Box-Cox specification tests for the six models we exhibit in table 2. The dependent variable is specified as $\left[\frac{PRICE^{\lambda}-1}{\lambda}\right]$, where $\lambda=1$ ($\lambda\to 0$) implies linear (semi-logarithmic) model. The test results, available upon request, yield rejection of both the linear and semi-logarithmic models at the 5% and 1% significance levels. The calculated Chi^2-statistics with one degree of freedom are: 4.73, 6.81, 4.46, 6.83, 3.99, 5.34 for $\lambda=1$, and 8.96, 8.62, 9.36, 8.61, 9.98, 10.28 for $\lambda\to 0$. The critical Chi^2-statistics with one degree of freedom are: 3.841 for the 5% significance level and 6.6349 for the 1% significance level.

$$\frac{d[PRICE]}{d(dB)} = [\alpha_1 + 2\alpha_2(dB) + 3\alpha_3(dB)^2 + 4\alpha_4(dB)^3][PRICE] \quad (4b)$$

Note that while substitution of $dB = 50$ in (4a) yields an incremental percent of price discount for the additional 1 dB of $\alpha_1 + 100\alpha_2 + 7{,}500\alpha_3 + 500{,}000\alpha_4$, substitution of $dB = 55$ in (4a) yields a different incremental percent of price discount for an additional 1 dB of $\alpha_1 + 110\alpha_2 + 9{,}075\alpha_3 + 665{,}500\alpha_4$. This is a prominent advantage of the polynomial model.

There are two a-priori reasons against the use of the linear specification, which implicitly imposes a fixed incremental housing price discount rate for each additional 1 dB (α_1, where $\alpha_2 = \alpha_3 = \alpha_4 = 0$), regardless of the level of traffic noise. The first reason is derived from theoretical considerations referring to hedonic models. Quigley (1982) stressed that unlike conventional competitive market theory, where the price per unit of good is fixed regardless of the amount consumed, in hedonic models, the implicit price of each housing characteristic is non-linear and vary with the amount consumed even at non-aggregated level. The second reason is that setting $\alpha_2, \alpha_3, \alpha_4$ to be zero, i.e., the conventional approach in the literature (e.g., Nelson, 1982), implicitly imposes $\frac{d[PRICE]}{d(dB)} = \alpha_1 PRICE$, namely, the assumption that environmental quality is a superior good (in the case that α_1 is statistically significant).[15] The model we propose is more flexible, and permits statistical examination of this implicit assumption.

4b. Results

Table 2 reports the regression outcomes. The dependent variable in all the regressions are ln[PRICE], the natural logarithm of the unit's price. In columns (1)

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[15] A superior good is characterized by a larger proportion of consumption as income rises. Nelson (1982) points out that the price of the house is a good indicator of the household's level of permanent income.

and (2) we run the full model specified by equation (4). The independent variables include dB^2, dB^3 and dB^4, where dB is omitted due to high degree of collinearity. In columns (3) and (4) the independent variables include dB and dB^2 (the traffic noise level measured in decibels and its square). In columns (5) and (6) only dB is included. The control variables in all the regressions include: HPI (housing price index), YEAR (year of transaction), AREA (unit's area measured in sf.), and ROOMS (number of rooms). The odd (even) columns (1),(3) and (5) ((2), (4) and (6)) report the regression outcomes of the full model (step-wise model, which includes only explanatory variables with significant coefficients at the 5%-1% significance level). The calculated F-statistics is a measure for the regression significance. Numbers in parentheses are standard errors. * significant at the 10% significance level. ** significant at the 5% significance level. *** significant at the 1% significance level.

As Table 2 indicates, the independent variables explain 81%-83% of the variation in the natural logarithm of the housing prices. The explanatory power of the YEAR variable is particularly high, as it explains 78% of this variation. Referring to the control variables, the coefficients of HPI and AREA are found to be statistically insignificant. Still, there is a significant and steady annual price growth of 10.20%-11.00% (significant at the 1% significance level). Increase in the number of rooms is associated with a significant rise of 4.10% in the housing values for each additional room (significant at the 5% significance level).

Based on the significant coefficients reported in columns (2) and (4) of Table 2, Figures 3 and 4 plot the projected housing price discount rate associated with incremental 1 dB as a function of levels of noise measured in dB. By combining equation (4a) with the significant estimates reported in column (2) and (4) of Table 2 we obtain: $2\cdot(4.48\cdot10^{-3})\cdot(dB(A))+3\cdot(-5.97\cdot10^{-5})\cdot(dB(A))^2$ and $45.24\cdot10^{-2}+2\cdot(-4.53\cdot10^{-3})\cdot dB(A)$. We plot Figures 3 and 4 by substitution of 50,51,52,53,54,and 55 dB - the on-sample levels of measured traffic noise.

Figures 3 and 4 demonstrate that indeed the capitalization of 1 incremental dB varies with the level of noise. While for the 50 dB level - we cannot reject the null hypothesis that housing price discount on the incremental 1 dB equals 0%, starting from the 51 dB level - this discount becomes negative and significantly different from 0% even at the 1% significance level. The housing price discount steadily and significantly decreases (at the 5% significance level) with higher noise levels, until it reaches -4.83% and -4.55% for the maximal level of noise of 55 dB. These outcomes indicate that the linear model, which yields a fixed estimate of between -0.987% and -0.953% regardless of the level of noise, may be mis-specified. While at the lower end of 50 dB and below, quiet seems to become a neutral and even an inferior good, as the noise level increases, quiet seems to become an increasingly superior good.[16]

Another aspect demonstrated by Figures 3 and 4 is the increase in the 95% confidence interval with the level of noise. For a 51 dB, the gap between the lower and upper bound of the 95% confidence interval is the smallest and is -1.09% and -1.04%, respectively. This gap steadily increases, until it reaches its peak at the noise level of 55 dB, where this gap reaches -6.93% and -7.96%, respectively. These outcomes imply that with the increase in noise levels, the preferences referring to this negative externality become heterogeneous, and depends on subjective level of susceptibility to this negative externality.

[16] Based on the estimation results of column (4) in Table 2, for example, the maximal point is obtained at the noise level of 49.93 dB ($=\frac{45.24\cdot10^{-2}}{2\cdot4.53\cdot10^{-3}}$). This outcome implies that within the range of 46.5 dB-49.93 dB (not shown in Figure 4) quiet is an inferior good, This result is consistent with the interpretation that the individual dislikes too much quiet.

5. SUMMARY AND CONCLUSIONS

Conventional hedonic theory describes the implicit price of each housing attribute as non-linear and increasing with the amount consumed (e.g., Rosen, 1974; Quigley, 1982; Follain and Jimenez, 1985). Yet, few studies account for this price non-linearity. The current study exploits unique micro data and special acoustic equipment to estimate the impact of highway noise on housing prices. A prominent advantage of our study is the location and nature of the examined neighborhood, which provides a natural experiment for the traffic noise externality.

Unlike other studies, we use polynomial curve fitting, which permits non-linearity in the implicit price of 1 dB. In accordance with the Doppler effect, results indicate a high level of traffic noise near the highway (68.0 dB), which significantly drops with distance from the highway, until it reaches the minimum level of 46.5 dB. Referring to incremental price discount with additional dB, compared with previous literature, we obtain higher estimates of 0.953%-0.978% per each additional dB.

Finally, research findings support the hypothesis that the implicit price of 1 dB is non-linear. Our findings suggest a significant increase in the incremental price discount per 1 dB with the level of noise from 0% at 50 dB to 5.91% at 55 dB. On the other hand, the spread of implicit price estimates becomes wider with the level of noise. One interpretation of these findings might be that the preferences referring to this negative externality become more heterogeneous with noise levels, and depend more heavily on subjective levels of susceptibility to this negative externality.

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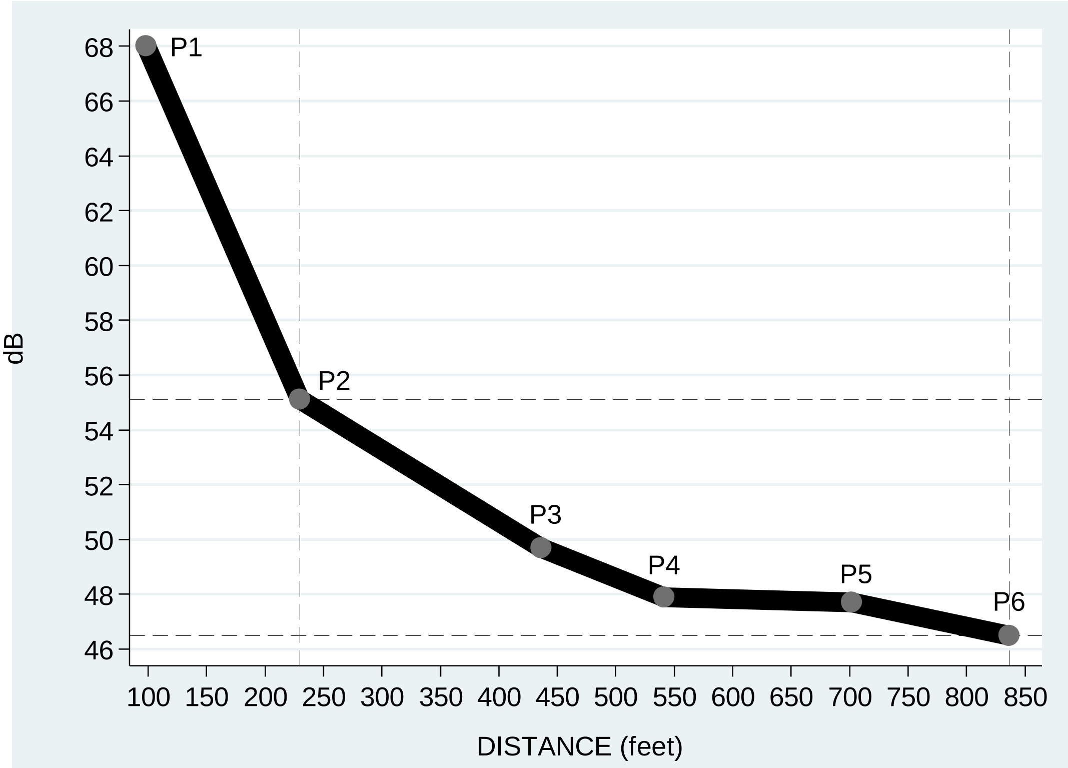
Figure 1: The Nechalem Neighborhood, Atlit

Notes: The red dots represent the six sites from which we sampled the readings of traffic noise in dB. These sites are denoted as P1,P2,P3,P4,P5 and P6, where P1 (P6) is the closest (most distant) site, to (from) the highway.

Figure 2: Variation of Traffic Noise with Distance from the Highway



Notes: The figure displays the traffic-related noise levels measured in dB as the distance from the highway to Haifa measured in feet. P1, P2, P3, P4, P5, P6 are the six points where readings of traffic noise were taken by the acoustic equipment. Readings were taken at March 4, 2012 (starting from 17:22 PM); March 18, 2012 (starting from 6:41 AM); and March 22, 2012 (starting from 6:21 AM). The dwelling units in the Nechalim neighborhood in Atlit stretch between points P2 (a measured noise level of 55.10 dB - 229.66 feet from the highway) and P6 (a measured noise level of 46.50 dB - 836.61 feet from the highway). A simple regression analysis between ln(dB) and distance from the highway reveals a statistically significant drop of 4.59% or 2.545 dB per each additional 100 feet from the highway (significant at a 5% significance level).

Table 1: Summary Statistics of Newly Constructed Units

A. Atlit

Variable	**Definition**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
PRICE	The non-deflated price of the dwelling unit converted to U.S. dollars	224	309,231	95,954.20	53,603	625,000
YEAR	The year in which the unit was sold	224	2007.75	3.35	2001	2016
HPI	Housing price index reflecting the average rate of increase in current new dwelling units in Atlit measured in percentage points	224	44.19	37.08	-3.42	153.53
AREA	The area of the dwelling unit measured in sq. feet	224	1,591.90	269.32	312.15	3,024.66
ROOMS	Number of rooms (not including kitchen or bathrooms)	224	5.296875	0.789527	1.00	7.00
FLOORS	The floor in which the unit is located	224	1.276786	0.530839	1	3

B. Nechalim Neighborhood

Variable	**Definition**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
PRICE	The non-deflated price of the dwelling unit converted to U.S. dollars	106	328,766	75,866.71	113,750	542,500
dB	Level of noise measured in decibels	106	50.56	3.84	46.50	55.10
YEAR	The year in which the unit was sold	106	2009.11	1.89	2004	2012
HPI	Housing price index reflecting the average rate of increase in current new dwelling units in Atlit measured in percentage points	106	39.58	26.11	$-3.58 \cdot 10^{-6}$	77.38
AREA	The area of the dwelling unit measured in sq. feet	106	1,637.53	195.02	861.11	2,303.48
ROOMS	Number of rooms (not including kitchen or bathrooms)	106	5.21	0.52	4.00	6.00

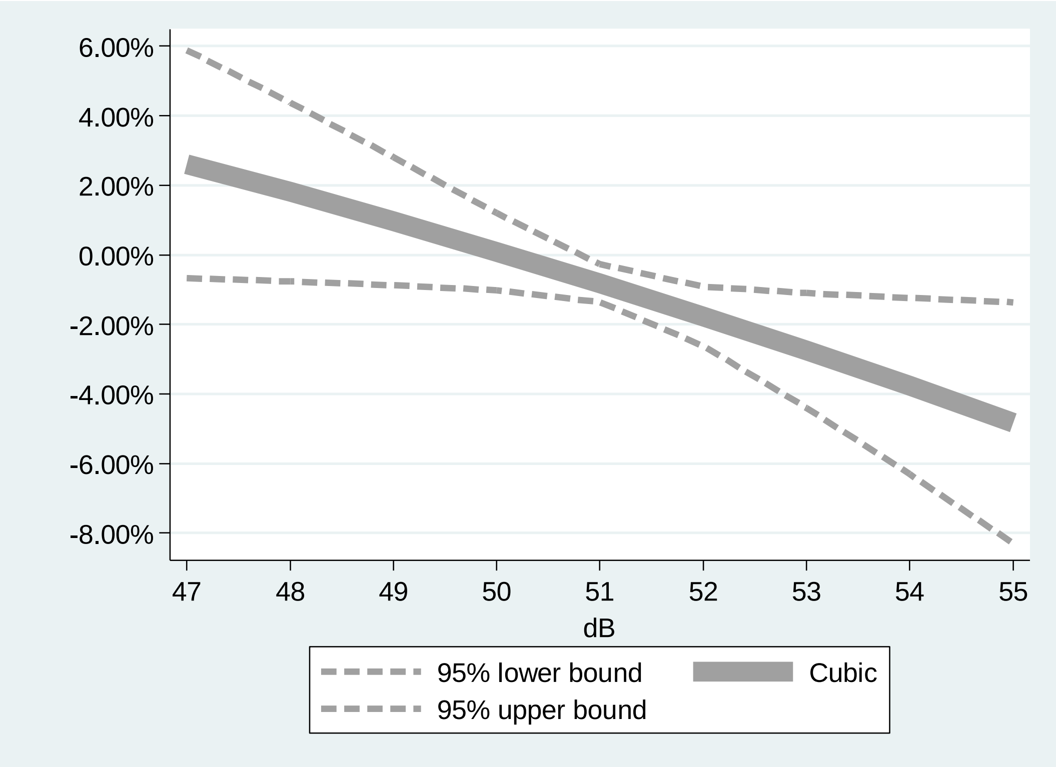
Notes: The descriptive statistics are based on transactions of single-family newly constructed housing units obtained from the Israeli Tax Authority. The upper (lower) part of the table refers to all reported transactions in Atlit (Nechalim Neighborhood in Atlit). Prices of the dwelling units are translated to US Dollars. The conversion rate is 1 US Dollar equals NIS 0.25, where NIS is the local Israeli currency.

Table 2: Hedonic Polynomial Regressions

VARIABLES	(1) ln(PRICE)	(2) ln(PRICE)	(3) ln(PRICE)	(4) ln(PRICE)	(5) ln(PRICE)	(6) ln(PRICE)
Constant	-291.30***	-212.10***	–210.20***	–219.70***	–191.70***	–210.20***
	(75.54)	(11.19)	(42.70)	(12.50)	(42.29)	(10.94)
dB	–	–	$41.30\cdot10^{-2}$ *	$45.24\cdot10^{-2}$ **	$-9.87\cdot10^{-3}$ ***	$-9.53\cdot10^{-3}$ ***
	–	–	(0.21)	(0.21)	$(2.83\cdot10^{-3})$	$(2.68\cdot10^{-3})$
dB^2	$21.60\cdot10^{-2}$	$4.48\cdot10^{-3}$ **	$-4.14\cdot10^{-3}$ **	$-4.53\cdot10^{-3}$ **	–	–
	(0.15)	$(2.12\cdot10^{-3})$	$(2.08\cdot10^{-3})$	$(2.03\cdot10^{-3})$	–	–
dB^3	$-5.71\cdot10^{-3}$	$-5.97\cdot10^{-5}$ **	–	–	–	–
	$(4.04\cdot10^{-3})$	$(2.75\cdot10^{-5})$	–	–	–	–
dB^4	$4.23\cdot10^{-5}$	–	–	–	–	–
	$(3.02\cdot10^{-5})$	–	–	–	–	–
HPI	$-2.33\cdot10^{-4}$	–	$-1.62\cdot10^{-4}$	–	$-3.17\cdot10^{-4}$	–
	$(1.44\cdot10^{-3})$	–	$(1.44\cdot10^{-3})$	–	$(1.46\cdot10^{-3})$	–
YEAR	$10.60\cdot10^{-2}$ ***	$11.00\cdot10^{-2}$ ***	$10.60\cdot10^{-2}$ ***	$11.00\cdot10^{-2}$ ***	$10.20\cdot10^{-2}$ ***	$11.10\cdot10^{-2}$ ***
	$(2.08\cdot10^{-2})$	$(5.43\cdot10^{-3})$	$(2.09\cdot10^{-2})$	$(5.43\cdot10^{-3})$	$(2.11\cdot10^{-2})$	$(5.45\cdot10^{-3})$
AREA	$6.48\cdot10^{-5}$	–	$5.64\cdot10^{-5}$	–	$8.04\cdot10^{-5}$	–
	$(6.08\cdot10^{-5})$	–	$(6.08\cdot10^{-5})$	–	$(6.04\cdot10^{-5})$	–
ROOMS	$3.71\cdot10^{-2}$ *	$4.10\cdot10^{-2}$ **	$3.74\cdot10^{-2}$ *	$4.10\cdot10^{-2}$ **	$3.30\cdot10^{-2}$	–
	$(2.02\cdot10^{-2})$	$(1.96\cdot10^{-2})$	$(2.03\cdot10^{-2})$	$(1.96\cdot10^{-2})$	$(2.05\cdot10^{-2})$	–
Observations	106	106	106	106	106	106
R-squared	0.83	0.82	0.82	0.82	0.82	0.81
F-Statistics	66.06***	115.07***	76.07***	115.14***	87.89***	212.20***

Notes: The dependent variable in all the regressions is ln[PRICE], the natural logarithm of the unit's price. In columns (1) and (2) we run the full model specified by equation (4). The independent variables include dB^2, dB^3 and dB^4, where dB is omitted due to high degree of collinearity. In columns (3) and (4) the independent variables include dB and dB^2 (the traffic noise level measured in decibels and its square) In columns (5) and (6) only dB is included. The control variables in all the regressions include: HPI (housing price index), YEAR (year of transaction), AREA (unit's area measured in sf.), and ROOMS (number of rooms). The odd (even) columns (1),(3) and (5) ((2), (4) and (6)) report the regression outcomes of the full model (step-wise model, which includes only explanatory variables with significant coefficients at the 5%-1% significance level). The calculated F-statistics is a measure for the regression significance. Numbers in parentheses are standard errors. * significant at the 10% significance level. ** significant at the 5% significance level. *** significant at the 1% significance level.

Figure 3: Cubic Model: Variation of projected Discount Rate Per 1 incremental dB

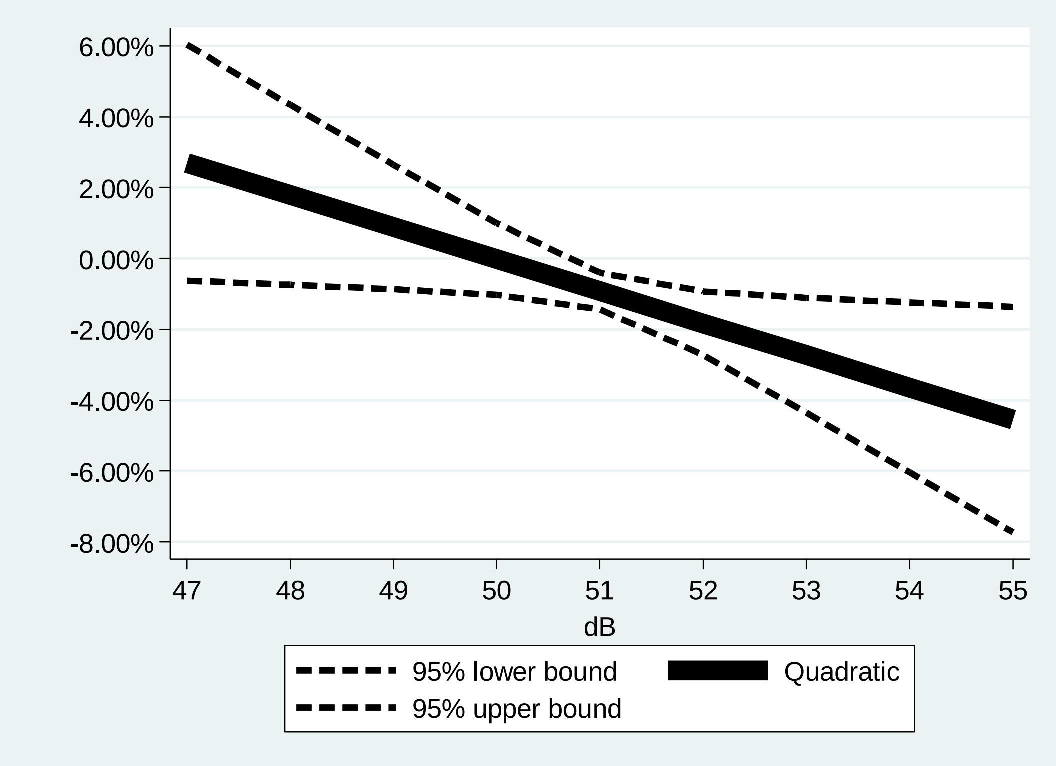


Notes: The vertical (horizontal) axis is the estimated discount rate on housing price per each additional dB (traffic noise measured in dB). Discount rates of the cubic model are based on the estimation results in column (4) of table 2. The estimated and significant coefficient of dB^2 is $4.48 \cdot 10^{-3}$ and of dB^3 is $-5.97 \cdot 10^{-5}$ (both are significant at the 5% significance level). The projected discount rate is based on the first derivative of ln(PRICE) with respect to dB, which yields $(2 \cdot 4.48 \cdot 10^{-3} \cdot dB) + (3 \cdot (-5.97 \cdot 10^{-5}) \cdot dB^2)$. The calculation results is specified in the following table:

dB	(1)	(2)	(3)=(1)+(2)	95% CI	99% CI	difference
47	42.15%	-39.54%	2.61%	(-0.67%, 5.89%)	[-1.73%, 6.95%]	–
48	43.05%	-41.24%	1.81%	(-0.76%, 4.38%)	[-1.60%, 5.21%]	-0.80%**
49	43.94%	-42.97%	0.97%	(-0.87%, 2.81%)	[-1.47%, 3.40%]	-0.84%**
50	44.84%	-44.75%	0.09%	(-1.02%, 1.20%)	[-1.38%, 1.56%]	-0.88%**
51	45.74%	-46.56%	-0.82%	(-1.36%, -0.27%)	[-1.54%,- 0.10%]	-0.91%**
52	46.63%	-48.40%	-1.77%	(-2.62%, -0.91%)	[-2.90%, -0.63%]	-0.95%**
53	47.53%	-50.28%	-2.75%	(-4.40%, -1.10%)	[-4.93%, -0.57%]	-0.98%**
54	48.43%	-52.19%	-3.76%	(-6.30%, -1.24%)	[-7.12%, -0.42%]	-1.01%**
55	49.32%	-54.15%	-4.83%	(-8.29%, -1.36%)	[-9.41%, -0.24%]	-1.07%**

where dB is the noise level; (1) equals $(2 \cdot 4.48 \cdot 10^{-3} \cdot dB(A))$; (2) equals $(3 \cdot (-5.97 \cdot 10^{-3}) \cdot dB^2)$; and (3) equals (1) plus (2). The 95% and 99% CI (Confidence Intervals) are given in (round) and [square] brackets. ** statistically significant at the 5% significance level.

Figure 4: Quadratic Model: Variation of projected Discount Rate Per 1 incremental dB

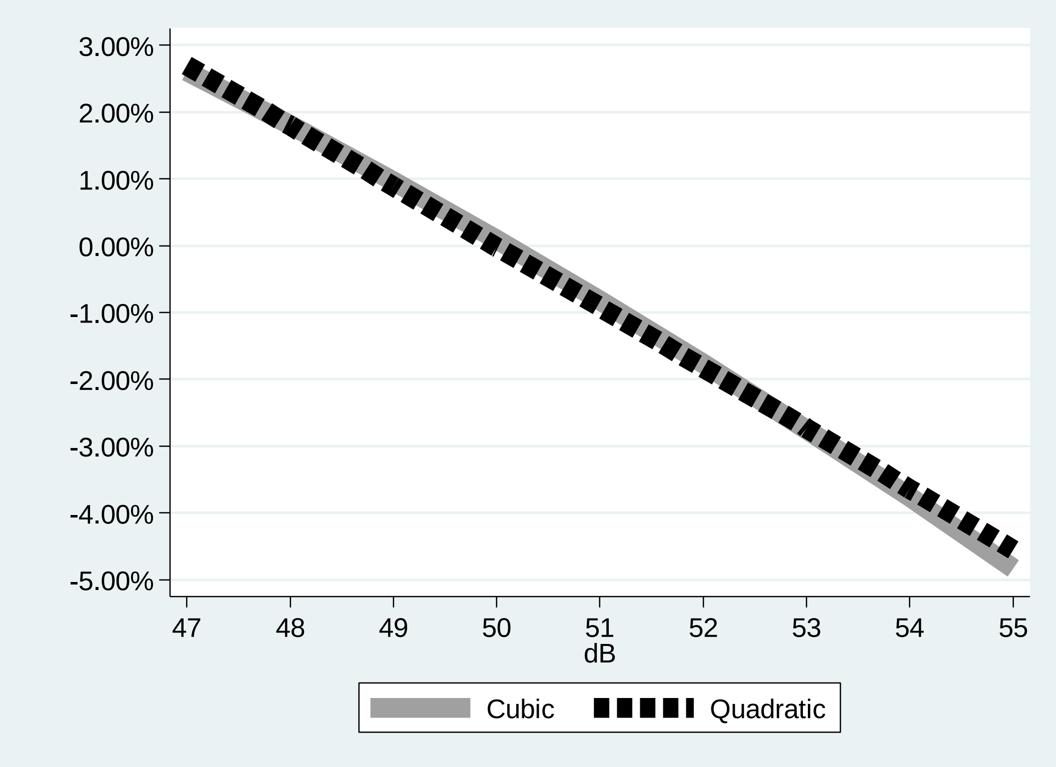


Notes: The vertical (horizontal) axis is the estimated discount rate in housing price per each additional dB (traffic noise measured in dB). Discount rates are based on the estimation results in column (2) of table 2. The estimated and significant coefficient of dB is $45.24 \cdot 10^{-2}$ and of dB^2 is $-4.53 \cdot 10^{-3}$ (both are statistically significant at the 5% significance level). The projected discount rate is based on the first derivative of ln(PRICE) with respect to dB, which yields $45.24 \cdot 10^{-2} + (2 \cdot (-4.53 \cdot 10^{-3}) \cdot dB)$. The calculation results is specified in the following table:

dB	(1)	(2)	(3)=(1)+(2)	95% CI	99% CI	difference
47	45.24%	42.54%	2.70%	(-0. 63%, 6.03%)	[-1.71%, 7.11%]	–
48	45.24%	43.45%	1.79%	(-0. 74%, 4.33%)	[-1.56%, 5.15%]	-0.91%**
49	45.24%	44.35%	0.89%	(-0. 87%, 2.65%)	[-1.44%, 3.22%]	-0.90%**
50	45.24%	-45.26%	-0.02%	(-1.03%, 1.00%)	[-1.36%, 1.33%]	-0.91%**
51	45.24%	-46.16%	-0.92%	(-1.44%, -0.40%)	[-1.61%, -0.23%]	-0.90%**
52	45.24%	-47.07%	-1.83%	(-2.72%, -0.93%)	[-3.01%, -0.64%]	-0.91%**
53	45.24%	-47.97%	-2.73%	(-4.35%, -1.11%)	[-4.88%, -0.59%]	-0.90%**
54	45.24%	-48.88%	-3.64%	(-6.03%, -1.24%)	[-6.81%, -0.47%]	-0.91%**
55	45.24%	-49.79%	-4.55%	(-7.73%, -1.36%)	[-8.76%, -0.33%]	-0.91%**

where dB is the noise level; (1) equals $45.24 \cdot 10^{-2}$; (2) equals $2 \cdot (-4.53 \cdot 10^{-3}) \cdot dB)$; and (3) equals (1) plus (2). The 95% and 99% CI (Confidence Intervals) are given in (round) and [square] brackets. ** statistically significant at the 5% significance level.

Figure 5: Quadratic vs. Cubic Model: Variation of projected Discount Rate Per 1 incremental dB



Notes: The vertical (horizontal) axis is the estimated discount rate on housing price per each additional dB (traffic noise measured in dB). The Cubic vs. Quadratic discount rates on housing values are given in the following table:

dB	Cubic	Quadratic
47	2.61%	2.70%
48	1.81%	1.79%
49	0.97%	0.89%
50	0.09%	-0.02%
51	-0.82%	-0.92%
52	-1.77%	-1.83%
53	-2.75%	-2.73%
54	-3.76%	-3.64%
55	-4.83%	-4.55%