Quasi-experimental evidence on the effect of traffic externalities on housing prices

Ioulia Ossokina and Gerard Verweij

CPB Netherlands Bureau for Economic Policy Analysis

P.O. box 80510

2508 GM The Hague

The Nethelands

i.v.ossokina@cpb.nl

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Abstract

This paper exploits a quasi-natural experiment to study the effects on house prices of traffic nuisance on local streets. As source of exogenous variation in traffic nuisance we use the opening of a new state highway in the Netherlands. This new highway led to a change in local traffic flows that altered the traffic density on the adjacent streets for some households, but left others unaffected. Controlling for spatial and house heterogeneity, we find that doubling of traffic density reduces housing prices with about 2%, what implies an upper value of traffic noise discount of about 0.5% per decibel. Our results indicate further that traffic nuisance discounts are likely to be misestimated in cross-sectional studies because nuisance tends to be correlated with omitted neighbourhood and housing amenities.

Key words: Traffic externalities; Quasi-experiment; Housing market; Hedonic approach; Repeat-sales; Fixed effects

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1 Introduction

Various countries provide national guidelines on the valuation of traffic nuisance in transport project appraisals (Odgaard et al., 2005). In these guidelines monetary values attached to nuisance are usually based on cross-sectional hedonic research using housing prices[1]. Recently there have been increasing concerns about the validity of the results of the cross-sectional hedonic studies on the valuation of environmental goods. These results are likely to suffer from the omitted variables bias as unobserved neighbourhood characteristics tend to be correlated with both, the housing prices and the environmental good (e.g. Greenstone and Gayer, 2009). To avoid this problem, our paper makes use of a quasi-experiment to study the valuation of traffic nuisance.

In line with the hedonic approach of Rosen (1974) we use residential sales data to infer an implicit price for reduced traffic nuisance. Hereby we exploit the variation in traffic density on local streets in the suburbs of the third largest Dutch city, The Hague, caused by the opening of a new highway in 2003. The opening of the highway can serve as a quasi-experiment in our study for the following reasons. First, the new transport connection considerably changed the traffic density on a number of local streets in the suburbs of The Hague leaving other streets unaffected. Second, one can argue that the highway-induced change in traffic density was largely unpredictable for the residents living on affected streets so that anticipation effects can be neglected. Before the opening there was hardly any publicity about the possible changes in local traffic flows the highway would induce[2]. Furthermore, the highway had two opposite effects on local traffic nuisance, of which the resulting impact at different locations was not known *ex ante*: (i) it absorbed the non-local traffic that previously used local streets; (ii) it created new local traffic flows heading for the highway.

Our data include sales prices of dwellings located on affected and unaffected local streets in the years before and after the opening of the highway. A noteworthy feature of our dataset is the continuous and longitudinal data on traffic density. Affected streets do not only differ in the level of traffic density in the before-period, but also in the magnitude of the change in traffic density caused by the highway. This variation allows us to progress beyond a simple comparison of housing prices on affected and unaffected streets and estimate a functional relation between traffic density and housing prices.

Taking advantage of our detailed data on traffic density we detect a statistically significant negative effect of an increase in traffic density on the value of houses within 40 meter from the

[1] Navrud (2004), Bateman (2001) and Nelson (2008) provide detailed overviews of the cross-sectional literature on the effects of traffic nuisance on residential values.

[2] There was much discussion about the highway self being a new source of nuisance for the immediate neighbourhood. In our analysis we control for this effect.

affected streets. The estimated elasticity of housing prices to traffic density is -0.02 for houses adjacent to the street; it is factor 2 to 4 smaller for houses located further away from the street. This measured effect accounts for the influence of a bunch of various local externalities induced by the traffic on local streets. As extensively described in Parry and al. (2007), these mutually correlated local externalities include among other things: congestion, noise, local pollution, accident risks. By taking account of various traffic externalities and focusing on the traffic on local streets, our study therefore amends existing quasi-experimental research on valuation of environmental goods (see Boes and Nüesch, 2011, and the references therein for airport noise; Palmquist, 1982, for highway noise; Chay and Greenstone, 2005, for the air pollution; Davis, forthcoming, for the nuisance from power plants) [3]. From the mentioned studies only Palmquist studies traffic externalities. He however uses variation in urban noise levels induced by a construction of a highway through a town, and does not take into account environmental effects of the local changes in the traffic flows brought about by the realisation of the new highway. These latter effects constitute the focus of our paper.[4]

Using our data, we furthermore estimate pooled cross-sectional models and find considerably lower effects of traffic nuisance (about 5 times as low). This suggests that traffic density in our data is positively correlated with omitted neighbourhood and housing amenities, causing cross-sectional estimates to be biased.

The paper proceeds as follows. In the next section we describe the institutional framework of the events related to the opening of the highway and explain our identification strategy. Section 3 deals with the data used and Section 4 presents the results and discusses their implications. Section 5 discusses various robustness checks and Section 6 concludes.

2 Research design

2.1 Highway-induced changes in local traffic density

As discussed in the introduction, we study the effects of the opening of the Dutch highway N14 that connected the highway A4 with the northern part of the third largest Dutch city, The Hague. Figure 2.1 shows a schematic map of the main street network in the surroundings of the new highway.

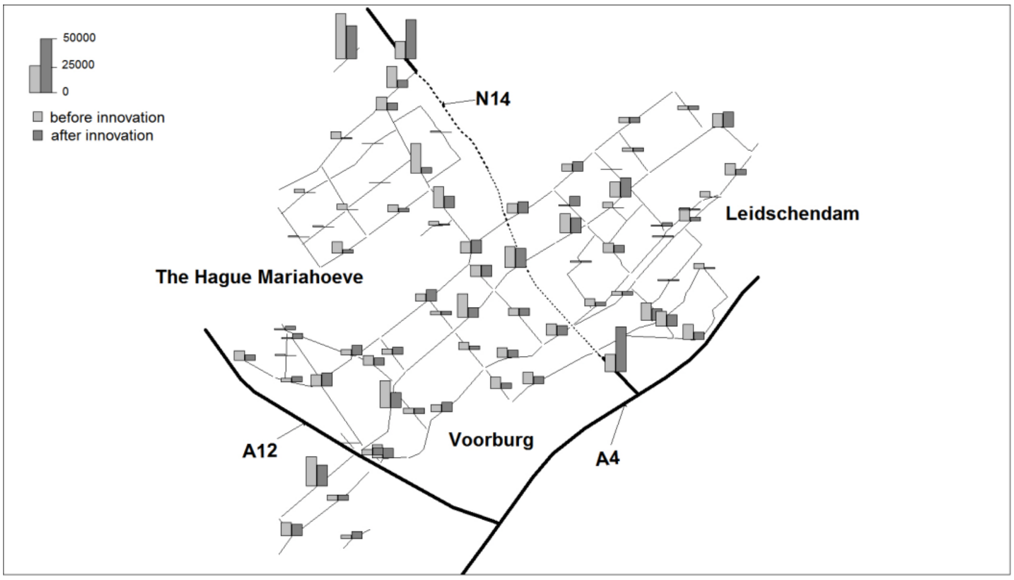
[3] And by focusing on external effects of traffic, our study amends the small quasi-experimental literature on the accessibility effects of new transport infrastructure. Klaiber and Smith (2010) study accessibility benefits of a new highway. Gibbons and Machin (2005) and Koster et al. (2010) study these benefits for new train stations.

[4] Furthermore, there exist two quasi-experimental studies that make a difference-in-difference analysis of the effects of changes in highway nuisance without having at their disposal micro data about the corresponding nuisance levels. Julien and Lanoie (2007) measures the effect of a noise barrier on the prices of houses in the immediate neighbourhood and Klaiber and Smith (2010) measure the nuisance effect of a new highway on the house prices in the immediate neighbourhood. Both papers approximate the level of traffic nuisance by the distance to the highway.

The N14 runs through the urban heart of the municipality Leidschendam-Voorburg and along the Hague neighbourhood Mariahoeve, and eventually connects to the existing main road infrastructure in the north of The Hague. The decision on construction of the highway was taken in 1995, works started in 1998, and in November 2003 the first cars made use of the new connection. To minimize nuisance effects of the highway on the immediate neighbourhood, the part of the highway between Leidschendam and Voorburg was built in three tunnels and the part of the highway located in The Hague was separated from the adjacent residential buildings by a sound wall.

Figure 2.1 Main street network in the surroundings of the new highway.

The thick lines are highways; the thin lines are local through streets; the dotted line is the new N14 highway. The bars indicate the traffic density on the streets before and after the opening of the N14.



Although relatively small in geographical scale, realisation of the new highway had important effects on the traffic flows in the region. On the one hand it absorbed the non-local traffic that previously used local streets to travel to the northern part of The Hague. On the other hand it created new local traffic flows heading for the new transport connection. Figure 2.1 shows the traffic density on through streets in the surrounding towns before and after the opening. Especially the decreases in traffic density induced by the realisation of the new highway were major: in the after-period some affected streets accommodated up to 90% less traffic than before, amounting to decreases by up to 15000 cars per day.

2.2 Identification strategy

In this paper we will exploit the described variation in traffic density before and after the opening of the new highway to analyse the (negative) valuation housing consumers attach to traffic nuisance. In other words, we will examine the impact of the change in traffic density on the prices of the dwellings that are affected by this traffic. In order to identify this effect properly, we will have to account for other effects that the new highway could have had on housing prices in its surroundings.

An important consequence for the residents of three surrounding towns[5] was improved accessibility. The new highway offers a faster connection than the alternative local routes. On basis of consultations with the transportation experts from the respective municipalities and taking into account the small geographical scale of the research area, we assume that the accessibility improvement was approximately the same within each of the three towns, but could have varied between the towns. Unfortunately, establishing a causal link between the opening of the highway and improved accessibility is not possible with our data due to the absence of a control area with no change in accessibility. For this reason we will not model the accessibility effect separately, but will include it in the general time trend and allow this trend to be town-specific.

Furthermore, it is probable that the realization of the new highway led to a change in the quality of living of the residents of adjacent dwellings. The northern part of the highway was realized above ground and a noise barrier was constructed to mitigate the negative external effects of the traffic. Nevertheless, it is possible that the residents of adjacent dwellings experienced a negative change in the quality of living due to the increased residual traffic noise and the appearance of a spatial barrier blocking the view. The southern part of the highway was built in tunnels to mitigate local nuisance and new residential housing (700 dwellings) and a park were realised on the top of the tunnels. This urban construction replaced open space. It is difficult to say in advance, whether this change in living environment positively or negatively affected the quality of living and the prices of adjacent dwellings. In our estimations, we will control for the possible effects on the adjacent dwellings by including dummies for spatial quality in the immediate neighbourhood of the highway.

The starting point for our analysis is the following regression[6] relating housing prices to the traffic density on the street where the house is located:

[5] Leidschendam, Voorburg, The Hague Mariahoeve.

[6] The regression equation is described as a panel structure. This notation is often used in the quasi-experimental literature for presentational convenience, although strictly speaking the dataset has a repeated cross-section structure. For the analysis, this distinction is not relevant (Imbens and Wooldridge, 2009).

$$\ln P_{it} = \alpha + \beta_1 \ln D_{it} + \beta_2 SQ_{it} + \gamma_1 X_{it} + \gamma_2 Y_t + \gamma_3 I_{LM,2004-2006} Y_t + f_{j(i)} + \varepsilon_{it} \qquad (2.1)$$

where

P_{it} is the price of dwelling *i* in year *t*,

D_{it} is the traffic density on the street where the house is located,

SQ_{it} is a dummy for a change in the spatial quality for houses adjacent to the new highway, with specific parameters for the part on ground level and the part in the tunnels,

X_{it} is a vector of the structural housing attributes of dwelling *i* in year *t*,

Y_t are year dummies accounting for the general time effect and $I_{LM,2004-2006} Y_t$ are the town-specific trends for Leidschendam and The Hague Mariahoeve (Voorburg is the reference),

$f_{j(i)}$ is the fixed effect of the location of the house, whereby function *j(i)* maps each house into a location defined as a postal code unit comprising a street or a part of a street,

ε_{it} is the residual term of house *i* in period *t*.

Note that equation (2.1) includes time invariant fixed effects on the level of a postcode unit. A single postcode unit includes on average 10 to 15 dwellings located on the same (part of a) street. The inclusion of time-invariant fixed effects assures that the parameters of interest are estimated within postcode unit groups, which reduces the risk of confounding variables substantially. We control for the variation in the structural characteristics of houses sold within one postcode unit by including covariates for these structural characteristics.

3 Data

3.1 Data description

This research uses two main sources of data: (i) information on housing sales between 1998 and 2006 in the towns Voorburg, Leidschendam and the neighborhood Mariahoeve in The Hague, and (ii) data on traffic densities on the through streets in the same region. Micro data on properties sold within the geographical area of our interest were kindly provided by the Dutch Association of Real Estate Brokers (NVM)[7]. These data include the transaction date, the transaction price and extended information on housing attributes, such as age, construction descriptors (e.g. type of heating, presence of a built-in garage, etc.) and various dimensional attributes (such as the size of the living area, the number of rooms, etc.) The data are geocoded[8], that is we know the geographical location of the dwellings and can determine the location of the dwellings with respect to other geographical objects. For example, we can determine which dwellings are located on through streets and/or in the direct proximity of the new highway. Our identification strategy (see Section 2) is based on repeated sales on the level of a postcode unit.

[7] Nationwide around 75% of all residential property sales is performed through a real estate broker who is member of NVM.

[8] We thank for the help with geocoding the data the department Spatial Economics of the Vrije Universiteit Amsterdam.

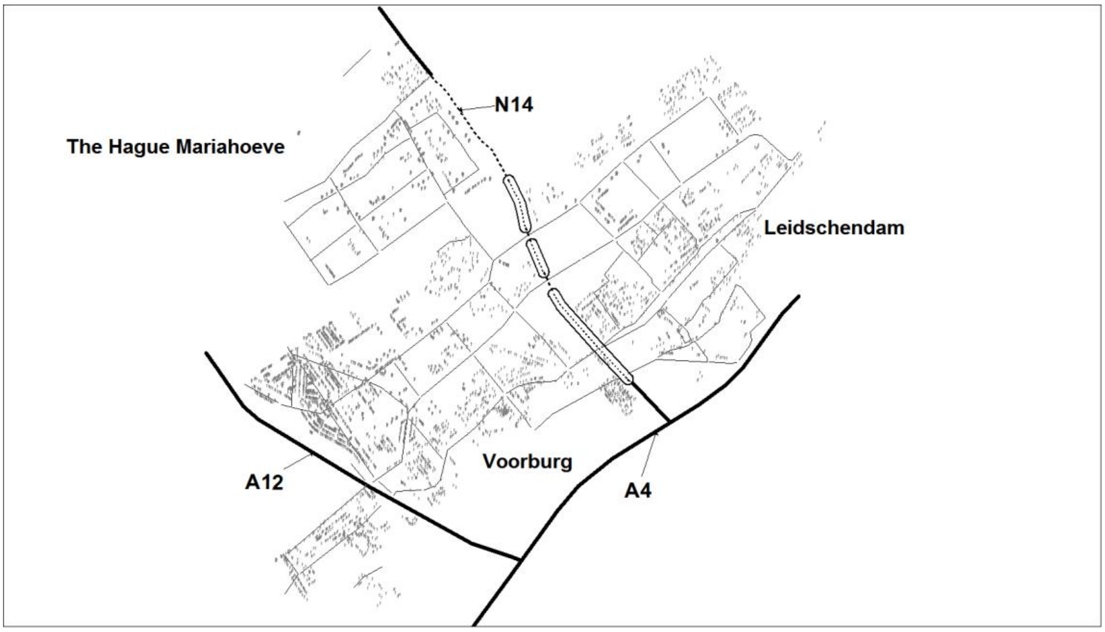
Consequently, we delete the observations in the postcode units that are present in the before- or after-period only. As a result we obtain an unbalanced panel consisting of 10503 observations within 1120 different postcode units. Roughly 60% of the observations refer to the period before the highway became operational (1998-2003), 40% of the observations refer to the after-period.

Detailed data on traffic densities on approximately 80 main street segments in the research area in the before- and after-period were kindly made available by the Municipality of Leidschendam-Voorburg. As illustrated in Figure 2.1 above, these data cover the through streets only. The absence of traffic density data for smaller (not through) streets[9] presents only a minor problem in our setting, as it can be argued that the realization of the new highway had no significant effects on the traffic density on these streets. Based on the knowledge of the exact geographical location of every dwelling and every street segment, the two datasets could be linked. Figure 3.1 below shows the geographical reach of our research area and the location of the dwellings in our dataset in relation to the main streets and the new highway.

Finally, information on social, economic and land-use characteristics of the location of the dwellings is taken from Statistics Netherlands. This information is used in our cross-section regressions only, as these characteristics are about constant over time and consequently drop out of the panel-based models.

[9] We construct the data for the non-through streets by taking the average density on these streets in 2006 (source: municipality Leidschendam-Voorburg) and correcting it for the average growth in the traffic in the region (source: Statistics Netherlands).

Figure 3.1 Geographical reach of the research area and location of dwellings sold.



Our dataset contains measurements of traffic density at two points in time: in 1999 and 2006. To obtain figures for the years 1998 and 2000-2005 we use the data of Statistics Netherlands on the growth rate of traffic on larger streets in the western part of the Netherlands. Table 3.1 reports these growth rates in terms of an index with year 2000 being a reference.

Table 3.1 Index traffic density larger streets (provinciale wegen) in the West of the Netherlands. Source: Statistics Netherlands. Year 2000 is the reference year.

	1998	1999	2000	2001	2002	2003	2004	2005
Index traffic density	94	98	100	102	104	105	105	106

3.2 Descriptive statistics

As a first step towards estimating the impact of the traffic density changes on housing prices, we compare housing and neighborhood characteristics for places that experienced a change in the traffic density and places that did not. In line with the policy evaluation literature, we term the affected dwellings 'treatment' group and those not affected 'control' group. Within the 'treatment' group we furthermore make a distinction into dwellings that experienced an increase in traffic density and dwellings that experienced a decrease in traffic density. Table 3.2 shows descriptive characteristics of the control and two treatment groups, and Appendix A provides descriptive statistics for the full dataset.

Table 3.2 Descriptive statistics: means, standard deviations are in parentheses

Variable	Treatment Group 1 (change traffic density <0) Before		After		Treatment Group 2 (change traffic density>=0) Before		After		Control Group (constructed traffic density) Before		After	
Price	170020		212305		208364		254648		182043		221559	
	(124558)		(149116)		(129453)		(135411)		(123461)		(143185)	
Traffic density												
(in thousand cars per day)	8.6	(8.5)	4.5	(4.9)	5.4	(3.2)	6.2	(3.0)	.26	(.01)	.27	(.001)
Structural attributes												
Living area in m^2	104	(48)	104	(46)	127	(51)	129	(49)	106	(43)	105	(42)
Number of rooms	4.2	(1.5)	4.1	(1.6)	4.9	(1.6)	4.9	(1.7)	4.3	(1.4)	4.1	(1.4)
Area in m^2	73	(370)	60	(129)	77	(153)	72	(134)	65	(196)	64	(169)
Dummy apartment	0.75	(.43)	0.75	(.43)	0.69	(.46)	0.68	(.47)	.70	(.46)	0.70	(46)
Dummy detached dwelling	0.03	(.16)	0.02	(.14)	0.02	(.15)	0.02	(.12)	0.01	(.10)	0.01	(.11)
Dummy side attached dwelling	0.07	(.25)	0.07	(.25)	0.06	(.24)	0.05	(.22)	0.09	(.28)	0.08	(.27)
Dummy two attached dwellings	0.04	(.19)	0.03	(.18)	0.02	(.14)	0.02	(.14)	0.02	(.15)	0.03	(.16)
Dummy middle attached dwelling	0.12	(.33)	0.13	(.33)	0.20	(.40)	0.24	(.43)	0.18	(.38)	0.19	(.39)
Dummy year of construction <1905	0.01	(.11)	0.01	(.09)	0.01	(.07)	0.01	(.10)	0.01	(.10)	0.01	(.10)
Dummy year of construction 1906-1944	0.33	(.47)	0.34	(.47)	0.66	(.47)	0.65	(.48)	0.33	(.47)	0.31	(.46)
Dummy year of construction 1945-1970	0.49	(.50)	0.58	(.49)	0.24	(.43)	0.26	(.44)	0.40	(.49)	0.46	(.50)
Dummy year of construction 1971-1989	0.15	(.35)	0.05	(.23)	0.04	(.20)	0.02	(.14)	0.21	(.40)	0.18	(.38)
Dummy built-in garage	0.10	(.30)	0.10	(.31)	0.12	(.33)	0.08	(.27)	0.14	(.34)	0.10	(.30)
Dummy hot water heating	0.09	(.29)	0.09	(.28)	0.16	(.36)	0.08	(.27)	0.10	(.31)	0.08	(.26)
Dummy ground rent	0.36	(.48)	0.33	(.47)	0	(0)	0	(0)	0.12	(.33)	0.11	(.31)
Dummy nice view (water. open space)	0.37	(.48)	0.42	(.49)	0.3	(.46)	0.34	(.47)	0.40	(.49)	0.45	(.50)
Dummy Located in Leidschendam	0.22	(.42)	0.24	(.43)	0.11	(.32)	0.12	(.32)	0.22	(.41)	0.22	(41)
Dummy Located in Voorburg	0.43	(.50)	0.42	(.49)	0.89	(.32)	0.88	(.32)	0.60	(.49)	0.60	(.49)
Dummy Located in DH Mariahoeve	0.34	(.48)	0.34	(.47)	0	(0)	0	(0)	0.18	(.39)	0.18	(.39)
Dummy <500m to N14 tunnel	0.07	(.25)	0.09	(.28)	0	(0)	0	(0)	0.04	(.20)	0.04	(.19)
Dummy <500m to N14 surface level	0.04	(.21)	0.05	(.22)	0	(0)	0	(0)	0.02	(.14)	0.02	(.15)
Land use and socio-economic characteristics neighbourhood												
% land under transport infrastructure	8.5	(5.1)	8.2	(4.2)	11	(4.9)	10	(4.5)	9.1	(5.0)	8.4	(4.7)
% land under shops and restaurants	2.3	(3.8)	2.2	(3.7)	3.5	(3.5)	3.6	(3.6)	3.2	(3.9)	3.0	(3.8)
% land under open space	6.4	(4.9)	7.4	(5.2)	6.7	(5.1)	6.9	(4.6)	8.0	(5.4)	9.3	(5.5)
% not western immigrants	13	(6.5)	16	(7.0)	11	(4.2)	12	(4.3)	12	(6.9)	14	(8.6)
Average income per household	14	(1.9)	15	(1.4)	14	(1.8)	15	(.84)	14	(2.0)	15	(1.9)
Population density in thousands people	7216	(2314)	7146	(2230)	8529	(1644)	8457	(1584)	7290	(2297)	7255	(2252)
Number of observations		835		448		369		205		4725		2924

Table 3.2 contains descriptive statistics for three groups of observations: (i) the observations lying on one of the through streets that experienced a fall in traffic density after the opening of the highway, (ii) the observations lying on one of the through streets that experienced a rise in

traffic density after the opening and (iii) the observations not lying on one of the affected through streets. The observations come from a sample covering Leidschendam, Voorburg and The Hague Mariahoeve. For each group of observations the before and after means and standard deviations are reported for the variables we will include in our regressions.

The first thing to note from table 3.2 is that the opening of the highway led to a major change in the traffic density in treatment group 1 amounting to an average reduction by 4000 cars per day. The average change in treatment group 2 was more modest with an increase of 1000 cars per day.

Furthermore, the table illustrates that the treatment groups and the control group match rather well in terms of the pre-treatment structural characteristics of the houses. They match less well in terms of the location of the dwellings. Especially treatment group 2 is strongly overrepresented in Voorburg and strongly underrepresented in The Hague, in comparison with the control group. This is a consequence of the fact that in the before-period Voorburg suffered less from through traffic than Leidschendam and The Hague Mariahoeve. As a result of the realisation of the new highway, Voorburg more often experienced an increase in traffic density than the other towns. To improve the control-treatment matching we allow the time trends to be town-specific. Besides, we will perform estimations for the three towns separately.

Finally, table 3.2 indicates that the percentage price changes between the before and the after period in the control and two treatment groups are in line with the expectations. The control group showed a price rise of 22% between the two periods. Treatment group 1, which experienced a considerable fall in the traffic density, showed a larger price rise (28%) than the control group. Treatment group 2, which experienced a modest increase in traffic density, showed a price rise (21%) that was marginally smaller than that of the control group.

4 How does traffic density affect housing prices?

4.1 Results from the regression model

In our data the traffic density does not vary within a postcode-year unit, and we apply postcode unit, $f_{j(i)}$, and year, Y_t, fixed effect estimators. Consequently, the only variation in traffic density we use is between the periods before and after the opening of the highway, within the affected postcodes. So, any measured effect of traffic densities on dwelling prices occurs through postcode unit-traffic density changes. Furthermore, we assume that without the new highway the traffic density on the streets in the control group and the streets in the treatment group would have grown with the same rate.

Effect of traffic density

Column 1 of table 4.1 below presents the estimated elasticity of the price of the homes adjacent to a through street to traffic density on this street. The estimated elasticity equals -0.02. This implies that a 1% decrease in the traffic density results in a 0.02% increase in the prices of houses affected by this traffic. The coefficient is highly significant.

Table 4.1 Baseline estimations for traffic density#

	Only houses adjacent to road (1)	Geographical range of 100 m. (2)	Geographical range of 40 m. (3)
Ln traffic density adjacent to street	-0.0179***	-0.0202***	-0.0190***
	(0.00523)	(0.00532)	(0.00525)
Ln traffic density for distance (0,20]		-0.0143***	-0.0102**
		(0.00524)	(0.00471)
Ln traffic density for distance (20,40]		-0.0103**	-0.00598*
		(0.00405)	(0.00308)
Ln traffic density for distance (40,60]		-0.00637*	
		(0.00386)	
Ln traffic density for distance (60,80]		-0.00412	
		(0.00349)	
Ln traffic density for distance (80,100]		-0.00229	
		(0.00257)	
Cross-term post-treatment * Town	YES	YES	YES
PC6 Fixed effects	YES	YES	YES
Year dummies	YES	YES	YES
Individual housing attributes	YES	YES	YES
R^2 within (adjusted)	0.765	0.766	0.766
number of observations treatment	1857	1857	1857
number of observations control	7649	7649	7649

#Coefficient estimates for the structural housing characteristics are reported in the Appendix.

The estimation in column 2 investigates the geographical range of the traffic nuisance effect. We find that homes located further away from the affected streets also profited from the fall in traffic density, although to a much smaller extent than the houses adjacent to the streets. This second order effect of traffic density change to further away located dwellings is significant up to the distance of 40 meter from the affected street. Column 3 presents the estimation in which only significant second order effects are included and finds the elasticity of prices of houses not adjacent to the street being between 0.006 and 0.01. This is factor 2 to 4 smaller than the magnitude of the first order effect on the adjacent houses. We will henceforth call the estimation in column 3 the baseline estimation.

Comparison with more conventional estimates

One natural question to ask is how much the use of the quasi-experimental method confers advantages in terms of pinning down the valuation of traffic nuisance. To shed light on this issue, we estimate a more conventional specification for cross-sectional data, with additional variables for the geographical characteristics detailed in the lower part of table 3.2. These estimates do not solely rely on the within postal code unit changes induced by a change in traffic density, but also on the spatial differences between postcode units.

The cross-sectional estimates are reported in table 4.2, column 2. They are based on data for the full sample with fixed effects defined on the level of neighbourhoods (neighbourhoods are larger statistical entities usually including a number of housing blocks and PC6 postal codes). The estimated housing price elasticity to traffic density is about 5 times lower than in the baseline estimation based on a quasi-experimental approach. This outcome suggests presence of other (positively valued) characteristics of the living environment that are highly correlated with the location on a busy street. One may think of such factors as: a wider view out of the windows, larger distance to the neighbouring houses and houses on the opposite side, the stately atmosphere, presence of trees, better accessibility, etc.[10]

Table 4.2 Comparison with conventional estimates

LN traffic density	(1) Baseline estimation	(2) Conventional cross-section estimates
adjacent to street	-0.0190***	-0.00400**
	(0.00525)	(0.00158)
distance (0,20]	-0.0102**	-0.00390**
	(0.00471)	(0.00180)
distance (20,40]	-0.00598*	-0.00359*
	(0.00308)	(0.00214)
R^2 within (adjusted)	0.766	0.831
Nobs treatment	1857	1857
Nobs control	7649	7649

4.2 Implications for the valuation of traffic nuisance

As car drivers self do not internalize the costs they impose on others, local authorities in many urban agglomerations take measures to reduce traffic externalities. In London and several other places around the world, vehicles entering the central parts of the city have to pay a congestion charge. Many European municipalities have adopted high parking costs in the inner city and built car parks at the urban boundaries near public transport hubs in order to keep cars out of the city. Governments furthermore invest in mitigation measures such as, for example, tunnelling of parts of transport infrastructure within urban boundaries.

[10] The reported estimates are for the years 1998-2003, the estimates for the years 2004-2006 are similar and for this reason not reported.

These measures reduce urban traffic externalities at a substantial cost to car owners and taxpayers. Designing cost-effective interventions requires insight into the benefits of traffic externality reductions. In different countries national guidelines on transport project appraisals contain monetary valuations to be used to estimate the benefits from reducing traffic noise. These values - mostly based on cross-sectional hedonic studies - diverge widely by country and by study (Navrud, 2004, Nijland and Van Wee, 2008). Our research suggests that, besides the regional differences in the valuation of traffic noise, estimation bias may account for the variation in the results. For our dataset we find that traffic nuisance is positively correlated with omitted neighbourhood and housing amenities, causing cross-sectional estimates to be biased.[11] Although the latest cross-sectional studies on noise valuation (Day et al., 2007, Andersson et al., 2010) exploit very detailed information on a large range of housing and neighbourhood characteristics, it stays a hard task to exclude all sources of omitted variables.

Let us consider the implications of our results for the valuation of traffic noise. Under the assumption that the only source of traffic nuisance is noise, one can express the effect of traffic nuisance found in our paper in terms of the noise discount (the so-called Noise Sensitivity Depreciation Index NSDI). The noise discount measures the reaction of housing prices (in %) to a decrease in noise with one decibel. As in general 1% less traffic results in a fall of noise nuisance with 0.04 decibel, the estimated elasticity of -0.02 implies an NSDI value of 0.02/0.04 = 0.5%. This result is somewhat higher than the effect found by Palmquist (1982) in the only study known to us that uses a quasi-experimental technique to estimate the noise discount. Palmquist reports a NSDI of 0.3% for the highway noise in the region of Seattle, Washington, US. Besides the regional differences in the valuation of traffic noise between the US and the Netherlands, the larger coefficient implied by the results of our study can be explained by the following intuition. Palmquist argues that the realisation of the highway in the case he studied hardly changed any traffic flows in the region; it is therefore likely that the effect measured had solely been caused by the change in noise. In our case however the effect measured concerns a whole bunch of traffic externalities, of which noise is only one. Comparing the result reported by Palmquist and our result one could make a somewhat speculative conclusion that ca 60% of the traffic nuisance can be explained by noise annoyance.

5 Robustness checks on the results

In this section we test the robustness of the estimates of the previous section for relaxation of different assumptions used in our analysis. First, we allow for different valuation of traffic

[11] Boes and Nüesch (2011) and Greenstone and Gayer (2009) provide more evidence on the existence of an estimation bias in cross-sectional estimates.

nuisance in different housing market segments. Second, we examine possible house price adjustment effects: anticipation effects on the one hand and slow price adjustment on the other hand. Third, we check whether our results are robust to allowing for different pre-treatment trends in the treatment and control group. Fourth, we relax the assumption of constant elasticity of housing prices to traffic nuisance.

Allowing for different effects in different housing market segments

It may be possible that the valuation of traffic nuisance differs between Voorburg, Leidschendam and The Hague, for example, due to the differences in income levels of the residents[12]. Furthermore, in Section 3 we have found that the match between the treatment and the control groups in terms of the location of the properties in one of the three towns, could be improved. To take into account possible town-specific differences in the valuation of traffic nuisance, we perform estimations for the three towns separately.

Table 5.1 Robustness analysis for market segments

LN traffic density	(1) Voorburg	(2) Leidschendam	(3) The Hague Mariahoeve	(4) Low Income	(5) High Income
adjacent to street	-0.0261	-0.0194	-0.0187***	-0.0191***	-0.0157
	(0.0196)	(0.0132)	(0.00649)	(0.00573)	(0.0102)
distance (0,20]	-0.0108**	-0.00591	-0.0151	-0.00869	-0.01213*
	(0.00531)	(0.00941)	(0.0142)	(0.00645)	(0.00697)
distance (20,40]	-0.00589	-0.0118	-0.00308	-0.00526	-0.00804
	(0.00380)	(0.00760)	(0.00486)	(0.00341)	(0.00612)
PC6 Fixed effects	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES
Year * City	NO	NO	NO	YES	YES
Post-treatment * City	NO	NO	NO	YES	YES
Housing attributes	YES	YES	YES	YES	YES
R^2 within (adjusted)	0.764	0.783	0.792	0.762	0.775
number of observations treatment	1053	361	439	802	1055
number of observations control	4584	1671	1394	3088	4561

The estimates are reported in columns 1 to 3 of table 5.1. Although the significance of the results becomes lower, the magnitude of the traffic density effect for the houses adjacent to the streets differs only slightly from that in the baseline regression. Results for the second order effect on the houses located further away from the through streets are less robust. A possible explanation stems from differences between the towns in the type of residential housing adjacent to the through streets, such as the height of the buildings.

[12] Day et al. (2007) suggest that people with higher income have a higher valuation of the amenity of quiet.

Next, we examine more explicitly whether valuation of traffic nuisance differs with the income level of the household. The idea behind this segmentation is that quiet is a luxury good valued higher by richer households. For every pc6 area, we determine whether it belongs to the 50 % most expensive houses (after correction for the general price trend) or the 50 % least expensive houses. In this way we consider the housing price to be a proxy for the income level of its inhabitants. For houses in both socio-economic groups a separate estimation is performed and the results are reported in column 4 and 5 of table 5.1. The coefficients are not significantly different from each other, so the hypothesis that the valuation of traffic nuisance depends on the income level of a household is not supported by our data.

House price adjustment effects

In this section we take into account that the effect of the change in traffic nuisance may have not been absorbed in the housing prices exactly after the opening of the new highway in November 2003. One reason is that adjustment of the housing prices to the new situation takes some time. Particularly, during 2004 some temporal traffic measures were in use to fine-tune the transport flows around the new highway. However, the reverse situation is also imaginable: anticipation effects may have taken place in the years preceding the opening, which could have resulted in price increases in those years. To test these two hypotheses we explore the robustness of our estimates by deleting 2003-2004 respectively 2002-2003 from the dataset.

Table 5.2 Robustness analysis for traffic density and house price adjustment effects

LN traffic density	(1) Baseline estimation	(2) Accounting for slow price adjustment	(3) Accounting for anticipation effects	(4) Accounting for deviating price trend in treatment groups	(5) Different valuation of traffic nuisance under and above 48 decibel
adjacent to street	-0.0190***	-0.0229***	-0.0212***	-0.0162**	
	(0.00525)	(0.00606)	(0.00586)	(0.00678)	
under 48 decibel					-0.0182
					(0.0111)
above 48 decibel					-0.0200
					(0.0152)
distance (0,20]	-0.0102**	-0.0132**	-0.0103*	-0.0102**	-0.0102**
	(0.00471)	(0.00559)	(0.00598)	(0.00471)	(0.00471)
distance (20,40]	-0.00598*	-0.00471	-0.00609	-0.00598*	-0.00597*
	(0.00308)	(0.00390)	(0.00410)	(0.00308)	(0.00308)
trend decreasing traffic intensity 98-06				0.00159	
				(0.00206)	
trend increasing traffic intensity 98-06				0.00250	
				(0.00267)	
R^2 within (adjusted)	0.766	0.774	0.786	0.766	0.766
Nobs treatment	1857	1440	1396	1857	1857
Nobs control	7649	5709	5750	7649	7649

Column 2 and 3 of table 5.2 give the results of the estimation. Slow adjustment of the prices to the new situation implies that the traffic density effect in 2005-2006 must have been higher than in 2004. Although column 2 indeed reports a slightly higher effect when the years 2003-2004 are deleted from the estimation, the difference with the baseline version is not significant. Presence of anticipation suggests that the effect of traffic density change must have showed itself before 2004, resulting in a downwards bias of the baseline estimate. This hypothesis is not supported by the results either: deleting the years 2002-2003 from the dataset results in a slightly higher coefficient than in the baseline estimation, but the difference is again not significant.

Deviating pre-treatment trends of the control and treatment group

In this section we test whether the estimated effects of traffic density have not been biased by a general difference between the treatment and control groups in the trend of the housing prices. We add to equation 2.1 a linear trend for the treatment group with a decreasing traffic density and a linear trend for the treatment group with an increasing traffic density. Column 4 of table 5.2 reports the results for this specification. The estimated coefficients for the group-specific trends are small and not significantly different from zero; the pattern of elasticity estimates remains unchanged.

Valuation of traffic nuisance at low and high traffic densities

An important source of traffic nuisance is noise. Literature on noise valuation usually assumes that there exists a threshold level, lying around the value of 50 decibel, above which a human ear experiences sound as annoyance.[13] In our analysis existence of this cut-off level would suggest that the valuation of traffic nuisance must differ above and below this cut-off level. At noise levels below 50 decibel other traffic externalities but for noise determine the valuation of nuisance; above 50 decibel noise adds to the bundle of traffic externalities leading to an increase in valuation of traffic nuisance. To test this hypothesis we estimate a piece-wise linear relationship between ln price and ln traffic density setting the cutting point to 1000 vehicles per day that corresponds to the noise level of roughly 50 decibel[14]. As column 5 of table 5.2 shows, the elasticities of housing prices on traffic density on both sides of the cutting point show no significant difference. If one believes in the existence of a noise threshold, then a possible - although speculative - explanation for this result would be that a marginal change in other traffic externalities but for noise (such as safety, air pollution) weighs heavier on low traffic streets than on busy streets.

6 Conclusions

In this paper we consider the relations between house prices and traffic density on the nearby located roads, providing new empirical support for the intuition that consumers negatively value traffic nuisance. We use a hedonic valuation model applied to the surroundings of the third largest Dutch city, The Hague, in the period 1998-2006. We implement a strong test based on a quasi-experimental change in traffic density on local streets as a result of the construction of a new highway. Our data not only contain information on which dwellings were affected by the highway-induced traffic density change, but also to what traffic density levels these dwellings were exposed in the before- and after -periods. Therefore, a detailed study of the relation between traffic nuisance and housing prices on the adjacent streets, is feasible.

We identify the elasticity of housing prices to traffic density on the adjacent street to be equal to -0.02. We furthermore study the geographical range of the traffic nuisance effect. Our findings suggest that the dwellings in the range of 0-40m from the affected streets have experienced some impact of the highway-induced traffic density change, although to a much smaller degree than the adjacent dwellings. We show that our estimates of the impact of traffic density changes on housing prices pass stringent tests and are robust for various changes in the underlying assumptions. Finally we compare the results obtained with the quasi-experimental method with cross-sectional estimates using the same data. Whilst the pattern is similar, the

[13] In different sources we have come across the values of 48 decibel, 50 decibel and 55 decibel.

[14] The calculation is made using the widely accepted in the Netherlands method for translating the traffic density into noise nuisance. (See www.stillerverkeer.nl/wegverkeerlawaai/SRMI, Standaard Rekenmethode I).

cross-sectional estimate is substantially lower indicating existence of a positive correlation between traffic nuisance and omitted neighbourhood and house amenities and, consequently, presence of an estimation bias. This result has implications for the valuation of road traffic externalities in transport project appraisals in different countries. Currently these valuations largely build on the outcomes of the cross-sectional hedonic studies on the effects of traffic externalities.

Let us conclude with the following side-note. Of course, the prices of dwellings are not solely determined by the present location characteristics, but also by the residents' expectations about the future environmental qualities of the location. The decision to construct the new highway N14 was already taken in 1995, while our dataset starts in 1998. The possible capitalization of the highway-to-come effects in the period after the announcement of the construction decision remains therefore out of our sight possibly leading to an underestimation of the effects. However, we think that it was fairly difficult for consumers to judge in advance to what degree the traffic on their street would be affected by the realisation of the highway. This argument is supported by our estimations for the period after 1998, where no significant anticipation effects were found. We expect therefore the anticipation effects to be modest.

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Appendix A Descriptive statistics full dataset

Table A.1 Descriptive statistics dataset, individual data

Number of observations: 9506

Variable	mean	stand.dev.	minimum	maximum
Sales price	197156	133335	50000	1000000
Traffic density	1.5	3.9	0	27
Structural attributes				
Living area in m^2	107	44	32	450
Number of rooms	4.3	1.4	1	12
Lot in m^2	65	205	0	10000
Dummy detached dwelling	0.7	0.46	0	1
Dummy side attached dwelling	0.013	0.12	0	1
Dummy two attached dwellings	0.08	0.27	0	1
Dummy middle attached dwelling	0.026	0.16	0	1
Dummy built-in garage	0.17	0.38	0	1
Dummy hot water heating	0.0097	0.098	0	1
Dummy ground rent	0.34	0.47	0	1
Dummy nice view (water. open space)	0.43	0.49	0	1
Dummy year of construction <1905	0.17	0.38	0	1
Dummy year of construction 1906-1944	0.12	0.32	0	1
Dummy year of construction 1945-1970	0.094	0.29	0	1
Dummy year of construction 1971-1989	0.14	0.35	0	1
Dummy year of construction 1990-1999 (reference)	0.41	0.49	0	1
Social-economic characteristics of the neighborhood				
Percentage not-western immigrants	13	7.4	2	45
Population density (persons per square kilometer)	7339	2266	222	12106
Income per person in € thousand	14	2	9.5	32
Land use in the radius of 500 meter around the property				
% land under transport infrastructure	0.088	0.049	0.017	0.28
% land under shops and restaurants	0.031	0.038	0	0.14

% land under open space	0.082	0.054	0	0.43
Year dummies				
Sold in 1998	0.08	0.27	0	1
Sold in 1999	0.08	0.28	0	1
Sold in 2000	0.1	0.3	0	1
Sold in 2001	0.11	0.31	0	1
Sold in 2002	0.13	0.33	0	1
Sold in 2003	0.12	0.33	0	1
Sold in 2004	0.13	0.33	0	1
Sold in 2005	0.13	0.33	0	1
Sold in 2006	0.12	0.33	0	1