Hedonic valuation of odor nuisance using field measurements, a case study of an animal waste processing facility in Flanders*

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Abstract

In this paper we estimate the external cost caused by odor from an animal waste processing facility in Flanders using new odor measures based on field measurements. We compare three different ways of incorporating odor nuisance indicators into the model: distance to the odor source, continuous odor measures, and a dummy variable approach comparable to the standard procedure in hedonic price analysis of noise pollution. We argue that the dummy variable approach is best suited to estimate the external costs and we test these specifications for a dataset of about 1400 observations of house sales transaction between 2004 and 2008. Results show that houses subject to moderate and severe odor nuisance sell at a discount of about 5% and 12% respectively compared to houses without odor nuisance. The overall capitalized external cost of the odor exposure for the area of the case study was estimated to range between 6 and 56 million euro, with a central estimate of about 31 million euro. This estimate proves to be very stable over different model specifications. Compared to 1991, the external cost has almost been cut by half as a result of odor emission reducing measures taken by the facility.

Keywords: valuation of environmental externalities, odor nuisance, hedonic price method, spatial econometrics

JEL codes: C31; Q25; R52

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1. Introduction

Land use choices such as the location of industrial facilities, water treatment plants, landfills or large scale animal farms often have important – negative – impacts on local living conditions. Residents from neighborhoods exposed to odor nuisance, i.e. bad smell, may consequently change their behavior and activities. Their outdoor recreation possibilities are likely to be restricted; such as children playing outside, people sitting in their garden and enjoying barbeques or family get-togethers. Also, when the bad odor is especially noticeable, residents might be reluctant to open their windows for ventilation. Moreover, industrial odors are not only an annoyance; they can also impair human health causing headaches, queasiness, sleep disorders, low appetite and stress (Shusterman, 1999).

In order to reach the socially desirable level of such local undesirable land uses, regulation is needed. However, the problem facing regulators is that little information exists on the extent of nuisance caused, making effective regulation much more difficult to achieve. In this paper we estimate the external costs inflicted by odor on residents close to a specific source of bad smell, namely an animal waste treatment facility in Belgium, i.e. a carcass destructor plant. To this end, we use the hedonic pricing method to look at variations in property values depending not only on the physical attributes of housing units, but also on neighborhood and environmental characteristics. Specifically, we focus on the methodological issues concerning the measurement of odor nuisance and we account for the typical spatial nature of this type of externality.

There are numerous examples of studies that estimate the external cost of pollution and nuisance using hedonic pricing methods for property values; see Boyle and Kiel (2001) or Palmquist (1999; 2005) for an overview and references. The origin of the hedonic approach to value goods with multiple characteristics dates back at least as far as Rosen (1974). Many of the subsequent hedonic studies focused on noise pollution caused by, for instance, airplanes or road traffic; see Nelson (2008) for a recent overview of the economic valuation of noise. Also air pollution has attracted a lot of attention; see, for example, Smith and Huang (1993). However, surprisingly few valuation studies address odor nuisance. A number of studies (examples include Nelson et al., 1992 and Reicher et al., 1992) have estimated the willingness-to-pay to reduce negative environmental effects of landfills for which the nuisance consists not only of odor but also of visual disamenities and externalities related to waste transport. Some papers, however, address odor nuisance explicitly, as cases in point Palmquist et al. (1997) and Herriges et al. (2005) study bad smells related to hog farms in the US, while Saphores and Aguilar-Benitez (2005) focus on industrial installations in Orange County California.

One of the reasons for the relatively small number of economic valuation studies for odor is probably the difficulty to measure in an objective and scientific way the intensity and discomfort caused by bad smell. The previously mentioned studies typically relied solely on measures related to the distance between the property and the source of the odor, although Herriges et al. (2005) also included a dummy for properties that were downwind to the hog farms. In the current paper we substantially improve the odor nuisance indicator by using field measurements of odor pollution instead of indicators linked to the (distance to the) source of the bad smell. Since the early 1990ies, the Flemish environmental authorities have commissioned odor measurement campaigns near the carcass destructor plant. Using a standardized protocol, test persons have detected the outer contours of the area in which odor is perceptible by humans. Using this outer contour, numerical simulation models have been used to interpolate odor contours. Hence, odor nuisance in this paper is based on real field observations collected in several campaigns between 1991 and 2008 on behalf of the Flemish environmental inspection authorities. Local topography and meteorological conditions are therefore reflected in the used odor indicators. We compare different ways of incorporating the odor exposure measurements in the model and conclude that a dummy variable approach distinguishing between three different levels of odor exposure (low, moderate and high exposure), or concentrating on a unique cutoff level which indicates a sizable exposure to bad smell works best in our case study. The dummy variable approach based on field measurements is able to reflect local characteristics of odor problems such as geographical and weather-related conditions as well as subject perceptions of odor by individuals (i.e. the character of the smell). Moreover, this approach reflects the spatial limits to what is essentially a localized nuisance problem and thus it has implications for the estimation of welfare effects. The use of dummies allows us to identify exposed and non-exposed zones in a manner that is consistent with the actual amount of nuisance caused. The use of continuous measures such as distance to the source, on the other hand, makes distinguishing between exposed and non-exposed zones – and the estimations of welfare effects – a much more arbitrary decision.

Furthermore, in recent years the hedonic price technique has been extended to account for spatial interactions that are often present in regional property transaction data. Typically, near things are more related than distant things, which leads to spatial dependence. It is well established that spatial clustering in observed or omitted variables can lead to biased estimates of the impact of environmental variables on property prices. See Palmquist (2005) for an overview of spatial hedonic studies and, for instance, Cohen and Coughlin (2008) and Andersson et al. (2010) for a recent applications to noise pollution caused by air and road traffic. In the current paper, we use spatial econometric techniques as a robustness check on the consistency of the estimates of the odor nuisance effect on property values, and hence on environmental external pollution costs.

Apart from estimating the welfare impact of noise exposure on a typical residential house, we use GIS techniques to estimate the total welfare costs of current odor nuisance. In addition, we are able to compare current odor nuisance to historical data of 1991. We show that, if the same level of odor nuisance of 1991 would still prevail today, welfare costs would be almost 75% higher than they are today. The reduction of the odor nuisance is largely due to extensive investments of the installation in odor emission reduction measures and we conclude that these investments have been strongly welfare enhancing.

In the next section we present some background information on the case. In section 3 we look in more detail at the measurement techniques for odor nuisance. In section 4 we specify the model and in section 5 we discuss the dataset we use for the hedonic valuation. The results of the analysis are presented in section 6, while the welfare effects are discussed in section 7. Section 8 concludes.

2. Background to the case

The case studied in this paper is an animal waste treatment facility located in Denderleeuw, Belgium, on the left bank of the river Dender. The centre of the municipality Denderleeuw is located at 750m southwest of the site, while the centre of neighboring town Teralfene (Affligem) is situated at 1000m southeast of the site. Moreover, the facility is also near to the municipality Liedekerke. The core business of the firm is the collection and processing of carcasses and animal by-products. In 2008, about 160 employees were working at the facility generating a turnover of about 55 million euros. All activities are subject to Flemish regulations based on Directive (EC) No 1774/2002 'animal by-products not intended for human consumption' of 3 October 2002.

The odor problem in the case study is caused by different types of firm related activities. The processing of animal waste is responsible for the larger part of the hindrance, but also road transport of animal waste adds to the nuisance affecting the neighborhood. The main source of nuisance comes from the input material in the facility's production process: dead animal waste and cadavers decompose and cause a repugnant odor of grease. Aldehydes, sulfur compounds and organic acids produce a pungent bad smell. Particularly the sulfur compounds have the largest odor nuisance potential (Van Broeck et al., 2005).

Over the past decade, the facility has implemented several costly technical measures such as the installation of bio filters and better insulation of processing buildings and transport lorries to alleviate the odor problem. However, the problem is still present and during the last few years, it does not tend to decrease significantly according to odor measurements (see below).

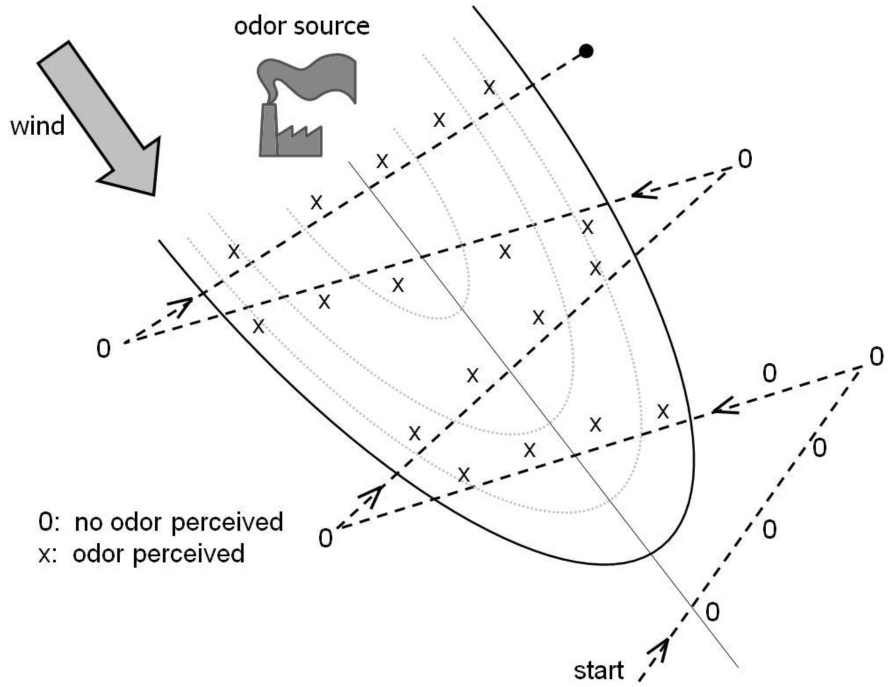
3. Measuring odor nuisance

Once odor is released from a source such as a chimney, factory hall or lorry, it is dispersed and diluted in the atmosphere. The concentration of the odor on release, the magnitude of emission, and the degree of dispersion and dilution that the odor is subject to during its journey from the source to the receptor are key factors influencing whether or not the odor is perceptible by humans. Both the odor emission and the feeling of annoyance (character of odor) should be taken into account when measuring odor nuisance.

Techniques available to measure odors can be broadly divided into chemical, sensory and sociological techniques (Van Broeck et al., 2005). Firstly, chemical methods use conventional analytical techniques to measure the concentration of specific odorous compounds within the sample gas. This can be achieved by the use of GC-MS (gas chromatography coupled with a mass spectrometer), specific chemical analyzers, indicator tubes and electronic noses. These techniques typically give more information about the constituent parts of the odor. Secondly, sensory techniques make use of human assessors to assess odor. Olfactometry involves taking an air sample and connecting it with a thinning device where concentrations are presented to panelists. They detect whether there is odor present in the samples. Sniffing measurement is the technique used in this case study and is extensively described in the next paragraphs. Other techniques also exist for the assessment of odor character, intensity and/or relative (un)pleasantness. Thirdly, through sociological techniques it is possible to assess the feeling of annoyance caused by bad smells. The complaints that are brought forward by affected persons are a first sign of an odor problem and analyzing these complaints can help to measure the extent of the odor problem.

PRG Odournet NV (a private environmental consultancy firm, see www.odournet.com) has conducted an odor study[1] for the animal waste treatment facility studied in this paper. To make a thorough evaluation of the situation, Odournet organized several sniffing measurement campaigns between 2004 and 2008. The results of those campaigns are then used to calculate odor contours and are thus the basis for this case study. Sniffing measurement campaigns are a commonly used technique in Flanders and Europe to estimate the impact of an odor emission source and for regulating the facilities involved.

Figure 1: Survey path of the sniffing team (Source: Van Broeck et al., 2000)



[1] See PRG Odournet (2007).

The maximum odor perception distance is determined by the sniffing measurements. Firstly the members of the sniffing team (typically 1 to 3 individuals) are familiarized with the specific odor that is to be detected. Then, they are sent downwind into the field, departing from a point where there is no odor perceptible. In order to prevent adaptation and missing the odor affected area, the research area is being crossed in a zigzag movement along the plume axis (see Figure 1). The route which is followed is marked on a topographic map while taking note of whether odor is observed or not.

The odor concentration at the maximum odor perception distance is calibrated, i.e. equated, to one sniffing unit per cubic meter: 1 su/m³. Thus the outer contour (see Figure 1) is determined and the odor affected area can be plotted. The size of the area depends on the meteorological situation at the time of measurement, the wind direction, the wind speed and the solar radiation (or cloudiness), these elements are simultaneously recorded. Detailed meteorological information for the test site during monitoring campaigns was provided by the nearest weather station in Semmerzake (at 30 km of the source). The odor emission characteristics (temperature of the emission gases and emission speed) and the height of the chimney are also influencing the size of the odor affected area, but these factors are averaged afterwards. The sniffing measurement campaigns are executed without previous warning during different meteorological circumstances. While conducting the observations, both the odor character as well as the specific source within the facility are determined if possible.

Olfactometry is well standardized on a European level (CEN, 1995, Harreveld et al., 1999), while the method based on sniffing measurements is still in the process of standardization[2]. Nonetheless, the sniffing methodology is already generally accepted and it is recognized to have some important advantages compared to conventional olfactometry. The main advantage is that the sniffing method involves real field measurements evaluating the global impact of the source, since diffuse, surface and other less clear sources such as waste handling are also considered (Van Langenhove and Van Broeck, 2001; Nicolas et al., 2008). Furthermore, this method reflects the actual perceptibility of an odor in the affected neighborhood, whereas with the olfactometric method the odor is perceived in artificial circumstances. Moreover, sniffing measurement is quite cost effective since any motivated and normal odor-sensitive person can do the observations and only two persons are needed.

After conducting several observations (minimum eight) in the area surrounding the facility, and comparing these results of the observations with the prevalent meteorological conditions at that time, it is possible to estimate the total odor emission. The BULMAL tool, developed by Bultynck and Malet (1972), was used to calculate points in a grid around the odor source which visualize the odor concentration[3] (su/m³) and duration of exposure[4] (98P). The results of the different measurement campaigns provide information on the maximum distance until where the odor is observable in a certain meteorological condition, downwind towards the

[2] For instance, the Flemish Government recently finished a study to develop a *code of good practice* in order to stimulate the standardization of this approach. See Bilsen and De Fré (2008).

[3] One sniffing unit per m³ is the odor concentration in the field where the odor is just observable for the field panel, (i.e. at the maximum odor perception distance).

[4] The 98-percentile ('98P') for 1 su/m³ indicates where the odor concentration exceeds 1 su/m³ at least 2% of the time. This means that on average the odor of the facility is observable 2% of the time.

source (i.e. the odor perception distance), on odor emissions and on the duration of exposure (see Table 1) .

Table 1: Results measurement campaigns

	2001	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
Number of observations	20	17	20	20	20	20	20
Odor perception distance (m)	1287	1527	1597	1400	1351	1707	1459
Odor emission (su/s)	154692	219763	158126	149155	167103	267919	249316
Average radius 1 su, 98P (m)	1043	1285	1056	1022	1091	1445	1383

PRG Odournet (2007)

Table 1 contains the basic data for the calculation of the odor concentrations in this case study. The maximum odor perception distance, observed by the members of the sniffing team, is incorporated in a short-term atmospheric dispersion model to calculate the odor emission rate (su/s) backwards. These calculated emissions are then used in a long term dispersion model to calculate the isopercentile contour plots. Since these odor contours do not form concentric circles around the emission source, the average radius of the odor affected area is also displayed in Table 1.

Using GIS (Geographical Information System) techniques it is possible to visualize these odor zones. Maps were produced (see Figure 4 and Figure 5 in Appendix) showing the odor zones for different years for which we have property sales prices at our disposal. Visual inspection of these maps reveals two things. First, compared to the odor contours in 1991, the area – and thus the number of people – subject to odor nuisance has considerably decreased. Secondly, the odor contours are not simple concentric circles around the emission source. Data of the Belgian meteorological service RMI (Royal Meteorological Institute) shows that the predominant wind direction in Belgium is southwest. The odor contour maps confirm this meteorological fact since the odor affected area is largest in the northeast.

4. Model specification

As shown by Rosen (1974), the marginal willingness-to-pay for attributes of composite goods will equal their implicit prices in an economy with utility maximizing individuals. The price of a house *(P)* therefore reflects the bundle of attributes associated with it, including structural, neighborhood as well as environmental characteristics. The hedonic price function can then be written as:

$$P = P(x_1, x_2, \dots, x_k),$$

where $X = [x_1, x_2, \ldots, x_k]$ denotes the vector of house, neighborhood, transaction and environmental attributes. This hedonic price function reflects a market equilibrium and can be used to value marginal changes in one of the attributes. If x_1 represents odor, the marginal willingness-to-pay (MWTP) for odor reductions can be estimated as:

$$MWTP = \frac{\partial P(X)}{\partial x_1}.$$

Note that this estimate can only be used for marginal changes in a particular attribute since it only reveals the MWTP in the market equilibrium and not for the underlying preference structure. Day et al. (2007) have developed a framework to calculate consistent values for non-marginal changes using estimates of preference parameters. However, in this study we assume that we are looking at marginal changes in the odor parameters since we are dealing with a localized problem (see also Palmquist et al, 1997 and Herriges et al., 2005).

5. Data collection and description

In order to estimate the effect of odor nuisance from the animal waste treatment facility on property prices, data on individual property sales transactions in the municipalities Denderleeuw, Liedekerke and Affligem were obtained from the Land Registry authorities (i.e. the public service which collects annual property taxes and which keeps track of individual house characteristics) and the Registration authorities (i.e. the tax authorities collecting a transaction tax on the sales transactions of houses) for the period 2004 to 2008. Recently the Land Registry database was linked with the Registration database so that an extensive dataset of property sales prices and characteristics was obtained. Approximately 1420 records were included in the analysis.

The dependent variable used in the analysis is the nominal sales price of a house including the sales transaction tax and the notary charges. Actual sales data are used since we assume that those sales come closest to reflecting true market trades (Clauw, 2007). For each transaction record, data were available on house and sale characteristics. These independent variables can be grouped in four categories: house characteristics, neighborhood characteristics, transaction characteristics and environmental data.

Firstly, the available data on house characteristics include dummy variables for: central heating, garden (taking value 1 if the garden surface exceeds 50m²) and renovation (taking value 1 if the house was substantially renovated less than five years before the sale). Other variables are: age (number of years since the house was built), house size (*i.e.* habitable area[5]), plot size, number of garages, number of bathrooms, and the property tax basis (*i.e.* a fictitious rent estimate, in € per month, which is the basis on which the property tax due is calculated).

[5] The habitable area is defined as the sum of the built-on area of the house and the surface of each floor. For each floor a correction factor is applied according to the accessibility and the application possibilities of the floor (e.g. a correction is made for the attic and bel-étages).

Secondly, with respect to neighborhood characteristics, the variables employed include the straight line distance (in km) to the nearest highway exit calculated using the X,Y co-ordinates of each record[6]. We also include the percentage Belgian citizens in the total population (per statistical sector[7]) and a dummy variable for the municipality in which the house is located.

Thirdly, transaction characteristics include dummy variables for: selling date (time dummy to account for yearly price effects) and whether the sales transaction was a public or a private sale.

Fourthly, the data also include information on the environmental characteristics. Regarding odor nuisance, different modeling strategies were implemented. The first strategy uses the straight line distance (in km) between the house and the source of the smell. These distances were calculated based on the geographical coordinates of the odor source and the property sold. Note that this approach has several disadvantages: it does not account for local meteorological and topographical aspects, it does not consider the subjective perception of the odor nuisance by the inhabitants nor does it impose boundaries on the area exposed to (local) nuisance. In contrast to the distance strategy, a second modeling strategy makes use of the field odor measurements and associated odor contour maps. This approach has the advantage that it relates more closely to the actual odor exposure and perception by the inhabitants of the affected area. We construct two dummy variable models. The first dummy variable model uses a unique cutoff value for the odor nuisance by defining a dummy variable OD for the zone where the measured sniffing units where above 2 su/m³. For the second dummy variable model, odor concentrations were classified in four categories: no odor nuisance (OD0), low odor nuisance (OD1), moderate nuisance (OD2) and strong nuisance (OD3). Since odor can be detected with certainty by humans above 1su/m³, zone OD1 is defined to contain odor contours starting from 1 to 2 su/m³ (not including upper boundary). Odor zone 2 (OD2) contains odor concentrations starting at 2 to 5 su/m³ (not including upper boundary). The zone with strongest odor nuisance (OD3) is characterized by odor concentrations larger than or equal to 5 su/m³. In addition to the dummy variable approach, we have also used continuous measures of odor in sniffing units (linear, quadratic and logarithmic specifications). Although one might think that continuous odor measures contain more information than crude dummy variable models and are thus to be preferred, one has to consider that, unlike the traditional noise decibel metrics like dB(a), there is no natural interpretation of the sniffing units scale. For instance, it is not clear what a doubling of the odor nuisance of 2 su/m³ to 4 su/m³ implies for the perceived odor nuisance by humans.

[6] Information about X,Y co-ordinates was obtained from an administrative list of addresses provided by the Flemish Agency for Geographical Information (http://www.agiv.be/gis/diensten/geo-vlaanderen/?catid=8).

[7] The area we consider consists out of some 40 distinct statistical sectors, *i.e.* the smallest geographical unit for which Statistics Belgium publishes socio-demographic data. In Figure 6 in the Appendix, one can see the delimitation of these statistical sectors within the municipal boundaries.

Table 2: Summary statistics

continuous variables	mean	median	standard deviation	minimum	maximum
age (years)	57.84	54	0.51	1	158
rooms (#)	5.33	5	0.23	2	16
bathrooms (#)	0.73	1	0.61	0	2
garages (#)	0.63	1	0.56	0	3
house size (are = 100m²)	1.51	1.46	0.36	0.34	6.16
plot size (are = 100m²)	4.61	3.40	0.93	0.49	42.95
property tax basis (€)	687.87	622	0.51	126	2664
distance highway (km)	2.93	3.05	0.33	0.21	5.53
share of Belgians	0.98	0.98	0.01	0.95	1
distance odor source (km)	2.16	2.10	1.03	0.26	4.98
odor (sniffing units)	1.01	0.5	1.80	0	15
price ($€_{2008}$)	206 157	197 305	84 883	31 425	594 868

dummy variables	count	percentage
selling year 2004	250	17.6%
selling year 2005	300	21.1%
selling year 2006	322	22.7%
selling year 2007	313	22.0%
selling year 2008	235	16.6%
renovated	104	7.3%
central heating	629	44.3%
garden	1309	92.2%
public sales transaction	52	3.7%
municipality Affligem	407	28.7%
municipality Denderleeuw	609	42.9%
municipality Liedekerke	404	28.5%
OD (odor ≥ 2 su/m³)	219	15.4%
OD0 (no nuisance, 0 ≤ odor < 1 su/m³)	1013	71.3%
OD1 (low nuisance, 1 ≤ odor < 2 su/m³)	188	13.2%
OD2 (moderate nuisance, 2 ≤ odor < 5 su/m³)	155	10.9%
OD3 (high nuisance, odor ≥ 5 su/m³)	64	4.5%

Table 2 reports summary statistics for our dataset. Some important observations can be made from this table. First, we have to warn against some of the structural characteristics of houses as recorded in the Land Registry authorities. The recorded characteristics do not always reflect the actual state of the houses as these characteristics are only updated when the owner applies for a permit for a major renovation of its house. Smaller renovations that do not affect the structure of the house, like for instance installing central heating, a bathroom or renovating the windows, are typically not picked up by the Land Registry database. The omission of these smaller renovations explains the low estimates of certain parameters in our dataset such as the fact that only 44.3% of the houses are reported to be equipped with central heating and that a substantial share of the houses are reported to lack a bathroom. On the other hand, more fundamental structural characteristics like house and plot size, or age and renovation can be considered to be accurate and reliable. Secondly, in order to present summary statics for the sales price in Table 2, we expressed all prices in 2008 prices, the last year in the dataset. We corrected for house price inflation by using price depreciations coefficients from a simple regression of the (log of) sales prices on sales year dummies. From this we derived that houses were on average 6% cheaper in 2007, 14% in 2006, 26% in 2005 and 42% in 2004 compared to 2008. We clearly recognize the effect of the economic crisis in the observed price evolution; whereas house prices were increasing by 16% between 2004 and 2006, the price increase decelerated in 2007 as can be seen from Figure 2 below.

Figure 2: Evolution house prices over time

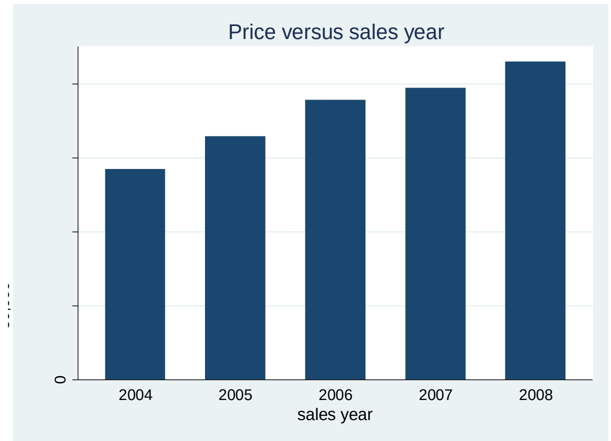
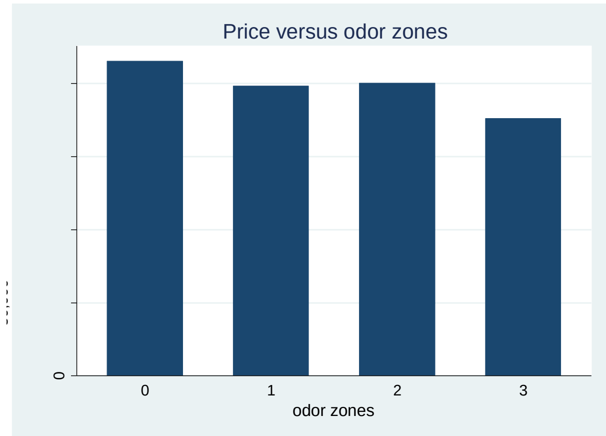


Figure 3: Relation price versus odor



A first view on the relationship between house sales prices and odor exposure is presented in Figure 3 which depicts average house sales prices in the four odor zones that we distinguish in the dummy variable model. Especially in the most exposed zone (OD3), average prices seem substantially lower than in other odor zones. Obviously, this is not a sufficient proof of a negative causal relationship between odor exposure and house prices since other houses or neighborhood characteristics might be responsible for the observed price differentials. Only a multivariate analysis of the data such as the analysis presented in the next section can provide additional insight in the relationship between odor and house prices.

Finally, in Figure 6 in the Appendix we present a map displaying the location of all houses being sold in the communities Denderleeuw, Liedekerke and Affligem between 2004 and 2008. Also selling prices are displayed on this map by means of the shading of the observation points. One can see from this map that there is strong geographical clustering of housing in the wider area.

6. Results

To estimate the hedonic price function, we start with ordinary least squares estimates of a semi logarithmic version of the hedonic house price model and we compare different ways to measure odor nuisance. Firstly, as a reference case, we incorporate distance to the source of the smell as an explanatory variable. This approach corresponds to drawing concentric circles around the pollution source and is unlikely to work well because smell is dispersed by wind which blows predominantly from the west in the center of Belgium. Secondly, we consider a dummy variable variant of the model using the four odor zones that were defined previously in section 3. In a third approach, we use one dummy variable for the zone where the measured sniffing units where above 2 su/m³. Next, we include a continuous measure of odor in sniffing units (and its square) as an explanatory variable in the OLS regression. And finally, we include the logarithm of the continuous odor measure. We also consider different spatial regression models to test robustness of the OLS estimates.

6.1 OLS estimation results

The results are presented in Table 6. First we describe some general trends with respect to the non-environmental variables. The estimated coefficients are all well behaved, i.e. they have the expected sign, are mostly significant at the 1% level and very stable across the different specifications of the model. We find that house prices increase with the number of rooms, with the presence of a garden, with the number of garages and with the number of bathrooms. Older houses sell at a discount. For instance, a 25-year old house is approximately 25 times 0.005 = 12.5% cheaper than a newly build house. Per additional 100m² of lot size, the sales price goes up with about 1.2%. Recently renovated houses are approximately 6% more expensive compared to non-renovated houses. Also, houses with a high basis for the property tax calculation are sold for higher prices. The elasticity of the sales price for a change in the property tax basis is about 0.4.

On the other hand, house prices are found to decrease with the distance to the nearest highway exit. For every additional kilometer from the highway exit, the price goes up with about 1.5%. Hence, a nearby highway exit seems a source of hindrance rather than an amenity. Further, we observe that houses at public auctions are sold at a lower price than houses sold privately. Houses offered at public auctions are on average some 20% cheaper than other houses.

Also, there are significant temporal effects in the house price data. On average, house prices increased about 12% per year during the period 2004-2008 in the area, but the effect of the economic crisis is clearly observable in the later years of the sample.

As described before, we report estimation results for six different specifications of the odor variable (represented by model 1 to model 6 in Table 6 in the appendix). First, we note that odor nuisance has a statistically significant negative effect on property prices in each of the specifications. Moreover, the magnitude and sign of the estimated coefficients for the non-odor characteristics are consistent over all specifications.

The first approach uses distance from source, expressed in kilometer, as proxy for odor nuisance (model 1). This yields a negative estimate for the impact of odor which is statistically significant at the 5% level. For every additional kilometer from the pollution source, house prices increase by about 2%. This result demonstrates one of the problems of using a continuous proxy for a local source of nuisance, namely that it is unclear at what distance one should stop assessing the source's impact on house prices.

The second approach uses dummy variables based on the field measurements to approximate odor nuisance (model 2 with four odor zones and model 3 with two odor zones). For the version with four odor zones, we find no significant effects for the first zone (OD1, low odor nuisance) but the coefficients for the second (OD2, moderate nuisance) and third zone (OD3, strong nuisance) are significant at 5% and 1% level respectively. Note that the estimated coefficients have to be transformed (see Halvorsen and Palmquist, 1980) in order to obtain the percentage change effect on the sales price of the house of being located in the different odor zones. Hence, houses in OD2 sell at a discount of 4.9% ($e^{-0.050} - 1 = -0.049$) and houses in OD3 sell at a discount of 11.5% ($e^{-0.122} - 1 = -0.115$).

Next, for the version with two odor zones, we also find a significant negative effect for the odor dummy (OD, sizable odor nuisance of more than 2 su/m³). This implies that houses in the zone OD sell at a discount of 7.56% ($e^{-0.0786} - 1 = -0.0756$). We conclude that odor has a negative and significant impact on house sales prices starting from a level of 2 su/m³. The sniffing unit scale is calibrated such that 1 su/m³ is perceptible for the human nose, but it takes a slightly higher value before people really start perceiving the odor as a nuisance and that this perception translates into lower house prices.

The third approach uses continuous variables for odor nuisance measured by means of sniffing units (model 4 with the number of sniffing units, model 5 with number of sniffing units and its square and model 6 with the logarithm of the number of sniffing units). Again we find statistically significant negative effects, except for the squared term which is not significant. Note that these estimated coefficients are difficult to interpret since it is unclear what the exact specification of the sniffing unit scale is. Hence it is unclear what a statement such as *'when odor increases with one sniffing unit per m³, the house price increases with 1.3%'* exactly means. We present the results with continuous odor measures for completeness and as robustness checks, however we believe that the dummy variable models are best suited for practical use.

6.2 Spatial estimation results

It is well established that ignoring geographical dependencies in observed or omitted variables could lead to biased coefficient estimates or inconsistent estimates of the standard errors (see for instance LeSage and Pace, 2009 for detailed arguments). If, for instance, strategic price setting behavior by home owners (or their agents) entails matching the price with the prices of comparable residences located in close proximity, the above OLS estimates could be biased.

Therefore, as a robustness check, we explicitly test for the presence and the impact of spatial correlation.

When incorporating the spatial pattern in the analysis, one can use a spatial autoregressive model (SAR), a spatial error model (SEM), or, a combination of both. The fundamental difference between SAR and SEM models lies in the way spatial lags are used to reflect the spatial dependencies. A spatial lag is in essence a linear combination of neighboring observations. For instance a spatial lag of our price variable could be defined as the spatially weighted average of the prices for houses in the neighborhood sold in the past. In the SAR model such a lag of the dependent variable is included as an additional regressor. This lag could capture for instance the impact of strategic price matching within the neighborhood. In the SEM model a spatial lag of disturbances of the non-spatial model are used to account for spatial dependencies in the error structure. This model specification might be more appropriate when the spatial pattern results from the spatial dependencies of unobservable characteristics of the houses rather than from strategic price interaction. In this setting at least one omitted variable in the model, like insulation against noise or unobserved neighborhood characteristics, is itself spatially dependent.[8]

Results for the combination of the SAR and SEM model for the same six specifications of odor nuisance are presented in Table 7 (see Appendix). The corrections for the spatial dependencies are never significant. Consequently, the coefficient estimates and significance levels for the house and neighborhood characteristics are very similar to the OLS estimates.[9] Hence, the spatial estimation acts as a robustness check of our results, but does not add additional insight compared to the OLS estimates in our case study.

7. Evaluation of welfare effects

Having estimated a significant impact of odor nuisance on the sales price of residential dwellings, we now use these estimates to obtain an approximation of the welfare cost caused

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[8] More formally, a general spatial model, incorporating both the SAR and the SEM model, can be represented by following set of equations: $\ln P = \rho W_1 \ln P + X\beta' + \varepsilon$, with $\varepsilon = \varphi W_2 \varepsilon + \nu$ and with P the vector of property prices, X a matrix of independent variables representing house, neighborhood, transaction and environmental characteristics and β its corresponding vector of coefficients. Errors ν are assumed independent and identically distributed. In this general model the spatial lag of the dependent variable would emerge as a nonzero value for coefficient ρ, while the spatial autocorrelation in the error term is captured by φ being nonzero. $W_1 \ln P$ ($W_2 \varepsilon$) is the result of pre-multiplying the price vector P (error vector ε) by a square weight matrix W_1 (W_2). A general weight matrix consists of N times N weight elements w_{ij}, reflecting the strength of the link between house i and house j, with N the number of observations. The diagonal elements of W are all zero, i.e. $w_{ij}=0$ if i=j and the rows of the weighting matrix are normalized to one. Assuming that prices of nearby houses have a stronger impact on the price of a particular house than prices of houses further away, we use the inverse of the distance between houses as spatial as input for W_1. As we only want to measure the price impact of house i on house j if house i is sold before house j, w_{ij} is set to zero when the selling date of i is after the selling date of j. For W_2 the selling date is less relevant so a symmetrical matrix containing the inverse distances is used. To account for the endogeneity of the spatially lagged dependent variable (see, for example, Brueckner, 2003), we estimate our spatial models by means of the spatial Maximum Likelihood (MLL) techniques developed by Anselin (1988).
[9] Other spatial model specifications, such as a pure SAR and a pure SEM model and alternative spatial weight matrices, reveal similar results.

by this environmental externality in the entire affected area. Welfare estimates are important as they can be used by the Flemish environmental authorities, for instance, to evaluate past odor nuisance regulation or to assess whether asking for more stringent odor emission reduction measures by the installation when negotiating a new exploitation permit is socially beneficial. It should be noted, however, that the calculations presented in this section underestimate the welfare cost, and thus provide a lower bound, because they only take the impact of odor on the welfare of residents living in the area into account. Impacts on employees of businesses, on students and teachers in schools, on elderly people living in rest-homes and so on are not captured by our approach and would have to be added to our estimates.

First, we estimate the welfare loss caused by odor nuisance during the time period 2004-2008. This estimate is to be considered as the welfare cost caused by current levels of odor nuisance. In a second step, we assess the change over time of the welfare cost of odor by comparing the exposed area in 1991 to the exposed area in the period 2004-2008. This comparison allows us to assess the value of the odor emission reduction measures that were implemented by the installation over the past decade.

7.1 Welfare cost of current odor nuisance

In order to calculate the welfare impacts for the entire area affected by odor nuisance, we use an average odor contour to determine the affected areas for different degrees of odor nuisance. We use the average odor exposure in the period 2004-2008 in order to limit the impact of year-to-year variations in odor nuisance caused by, for instance, differences in atmospheric conditions and production volumes or by one-off incidents in the production process.

First, we need to know the total number of residential dwellings in the affected areas. However, the information in our house sales transaction database covers only a small sample of the total population of houses and accurate information on the total stock of occupied residential houses is not publically available on a systematic basis. For these reasons, we have chosen to approximate the number of houses by using an estimate of the number of households living in the area. In particular, we approximate the number of households per statistical sector, and hence residential dwellings per sector, by dividing the population in the sector by the regional average household size (i.e. 2.38 persons per Flemish household in 2006 according to Statistics Belgium). Secondly, using GIS techniques, we allocated the total number of households to the different odor nuisance zones per statistical sector. For this allocation, we use the sample of houses sold as a proxy for determining the shares of houses in a particular odor zone and statistical sector. This is a valid approximation in so far as the sample of house sales transactions is representative for the total stock of houses. As can be seen from Table 3, our approximation (column 1) matches closely the latest available data on the number of houses according to the socio-demographic survey of 2000 (column 2). We also observe in the last column that the propensity to sell a house, i.e. the number of sales transactions in the period 2004-2008 (column 3) divided by the number of houses (column 2) is relatively stable over the different odor zones. Only for the most exposed odor zone OD3, we observe a slightly higher propensity but this is also the zone with the lowest number of observations and thus the proxy for the propensity to sell is likely to be less accurate.

Table 3: number of residential houses in different odor zones

	[1] Estimated number of households	[2] Houses (survey 2000)	[3] Sales transactions (2004-2008)	[4] Sales propensity in 2004-2008
OD0	12629	11392	1013	10.0%
OD1	1977	1841	188	11.0%
OD2	1492	1488	155	10.9%
OD3	624	576	72	12.6%
Total	16722	15297	1428	10.3%

Table 4 reports welfare cost estimates taking into account the average odor contours for the period 2004-2008. First, we observe that houses in the moderately exposed area OD2 sell at an average discount of about 10510€ compared to houses in the non-exposed zone OD0. This discount for houses in the most exposed zone OD3 amounts to 24750€. These numbers can be used to evaluate marginal changes in odor exposure. If, for instance, new odor emission reduction measures by the installation would result in a decrease of the number of houses exposed, the marginal welfare gain of this is 24750 – 10510 = 14240€ for each house that moves from OD3 to OD2, and 10510€ for houses that move from OD2 to OD1 or OD0. Secondly, we observe a one-off capitalized welfare cost[10] of -15.7 million € for moderately exposed houses in OD2 and -15.4 million € for highly exposed houses in OD3. In total, the welfare cost is about 31.1 million € for the entire area. Note that we did not take into account the houses in odor zone OD1 because the estimated price depreciation coefficient was not significantly different from zero[11].

Table 4: Welfare cost estimates 2004-2008

	Estimated number of houses	Estimated relative price decrease compared to OD0	Price decrease per house (million $€_{2008}$)	Total welfare cost estimate (million $€_{2008}$)		
				Lower 95%	Mean	Upper 95%
OD1	1977	0.0%	0	0	0.0	0
OD2	1492	4.9%	10510	0	-15.7	-32.0
OD3	624	11.5%	24750	-6.4	-15.4	-23.9
Total (capitalized)				**-6.4**	**-31.1**	**-56.0**

[10] This cost is considerably lower than an earlier estimate in De Meyer (2008) who estimated total environmental damage to about 51.7 million since we only take odor nuisance into account from 2 su/m³ onwards and we use a more accurate approximation of the number of households in the different odor zones.

[11] As a sensitivity analysis, we also computed the welfare cost using model 4, with only one odor zone dummy for houses exposed to 2 su/m³ or more. The resulting price decrease per house was estimated to be 7.6% or 16.369€. As there are 1492 + 624 = 2.116 houses exposed to 2 su/m³ or more, the total welfare cost amounts to 34.6 million €, about 10% higher than the estimate in Table 4 but still comparable in magnitude.

Using the 95% confidence intervals on the estimated price depreciation coefficients, we can construct confidence intervals for the welfare cost estimates. As shown in Table 4, the capitalized welfare cost estimate ranges between 6.4 and 56.0 million €.

7.2 Change in welfare between 1991 and 2008

Over the years, the industrial facility has invested heavily in odor reduction measures. For instance, for one of its main production lines processing poultry animal waste, it is documented[12] that the company invested for about 4 million euro to limit odor emissions between 2000 and 2004. Also the odor contour maps (see Figure 5 in Appendix) show a substantial decrease in the areas affected by odor nuisance between 1991 and 2009. In order to compare these investments to the change in welfare cost over time, we repeat our welfare cost estimation using the oldest available odor contour which dates back to 1991. Using GIS we located the houses of our sales transaction database against the 1991 odor contour and we approximated again the number of exposed houses under the hypothesis that the odor nuisance of 1991 would prevail today. Since odor contours were substantially larger in 1991, the estimated number of affected houses in each zone is also substantially larger. The resulting welfare cost estimate can thus be interpreted as the hypothetical odor welfare cost if the old odor contour of 1991 would still apply. Table 5 reports these estimates.

Table 5: Welfare cost estimate 1991 odor contour

	Estimated number of houses	Estimated relative price decrease compared to OD0	Price decrease per house (million $€_{2008}$)	Total welfare cost (million $€_{2008}$)
OD1	4143	0.0%	0	0.0
OD2	2091	4.9%	10510	-22.0
OD3	1310	11.5%	24750	-32.4
Total (capitalized)				-54.4

It turns out that the welfare cost decreased by about 54.4 – 31.1 = 23.3 million euro between 1991 and the period 2004–2008. This number can be interpreted as the environmental damage saved or avoided by investing in odor emission reduction techniques. Comparing the reduction in odor nuisance with the order of magnitude of the investment costs, the cost-benefit balance is clearly positive. The decrease in welfare costs thus outweighs the investment costs.

[12] According to the answer of the Flemish Minister of Environment Mrs. Schauvliege in response to parliamentary question nr 50 of October 12, 2010.

8. Conclusion

In this paper we estimated the external cost caused by odor nuisance for an animal waste processing facility, i.e. a carcasses destructor plant, in Flanders, Belgium. In contrast to previous studies that typically rely on distance measures to the odor source, we made use of detailed odor field measurements to account for the nuisance in our hedonic regression analysis. The odor measures we use are based on monitoring campaigns by sniffing teams and these campaign results serve as inputs for numerical simulation models producing odor contour maps for the affected region. We compared three different ways of incorporating measures of odor nuisance into the model: (1) straight line distance to the odor source, (2) dummy variable approaches classifying houses as (slightly / moderately / heavily) affected or not, and (3) models using continuous odor indicators measured in so-called sniffing units. We believe that the dummy model approach is best suited for analyzing the effect of odor nuisance. The distance approach suffers from the fact that it does not account for atmospheric and topographical influences. Hence, the assumed correlation between distance to the source and actual odor exposure is not always justified. The continuous odor measure is problematic as well because it is not clear how changes in sniffing units relate to changes in perceived odor nuisance. In particular, the sniffing units scale does not allow for intuitive interpretation as for instance the standard noise measures. Moreover, using continuous measures for estimating welfare effects of a localized nuisance problem involves the imposition of an ad hoc cut-off level that is only loosely related to the underlying problem. The dummy variable approaches does not have these inconveniences and was shown to work well for the case study area.

We tested the different models using a dataset of about 1400 house sales transactions in the period 2004-2008. The dataset did not reveal significant spatial effects and hence, for our case study, it did not prove necessary to account explicitly for spatial interactions in the hedonic property value model. However, the spatial regression results illustrate the robustness of the estimated coefficients. Our OLS estimates show that it takes a value of about two sniffing units per m^3 before a significant negative effect of odor exposure on house prices can be detected since the coefficient for the low nuisance zone was not statistically significant. This is more than the perception threshold of one sniffing unit per m^3 that is used to calibrate the odor measurement scale and to construct odor contour maps. Moderately affected houses suffer a price decrease of about 5% compared to houses in the unaffected reference area. The price decrease amounts to almost 12% for houses in the most strongly affected zone. After using these estimates to approximate the impact on the entire area suffering odor nuisance, we found that the overall external cost of the odor exposure is approximately 31 million € in capitalized house value. Comparing current odor nuisance with observations from 1991, we can also conclude that the odor reduction measures implemented by the installation have led to a significant decrease of about 23 million € in external welfare costs. From a societal cost benefit point of view, the implemented odor reduction measures were clearly worthwhile.

Detailed study of the data for the test case area has revealed some unresolved issues that might be taken up in extensions of this paper. First, several sources of nuisance interact in the study case area. There are some important sources of traffic noise (a major highway E40 and railway line Brussels – Ghent) crossing through the middle of the odor exposed area. We observed in our estimation results, for instance, that distance to the nearest highway exit is rather a disamenity than an amenity in the study case area. Also the lorries loaded with animal waste cause considerable external costs (local air quality and noise) for local inhabitants. The interaction of several sources of externalities is a potentially important issue not taken up in our paper due to lack of appropriate data on other externalities. Secondly, it would be interesting to complement this externality cost estimate with results from alternative valuation techniques (CVM in particular) to test for robustness of results and to account for other types of valuations (non-use values for instance) which are not picked up by revealed preference methods like hedonic pricing models.

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Appendix

Figure 4: Average odor contours (2004 – 2008)

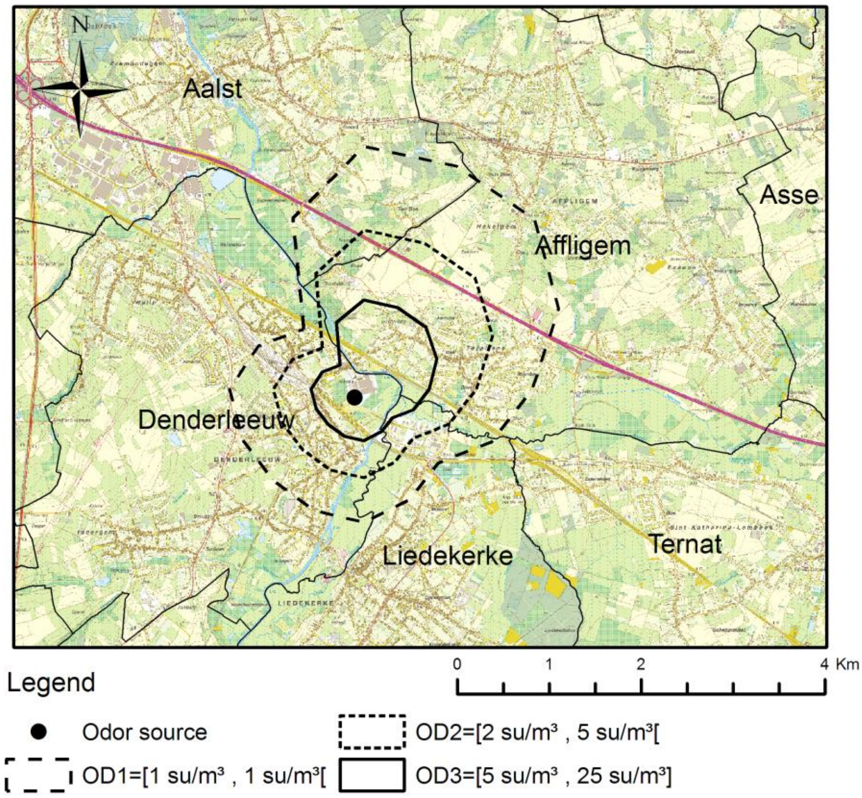

Figure 5: Evolution odor contours over time

Odor contours 1991 **Odor contours 2004-2008**

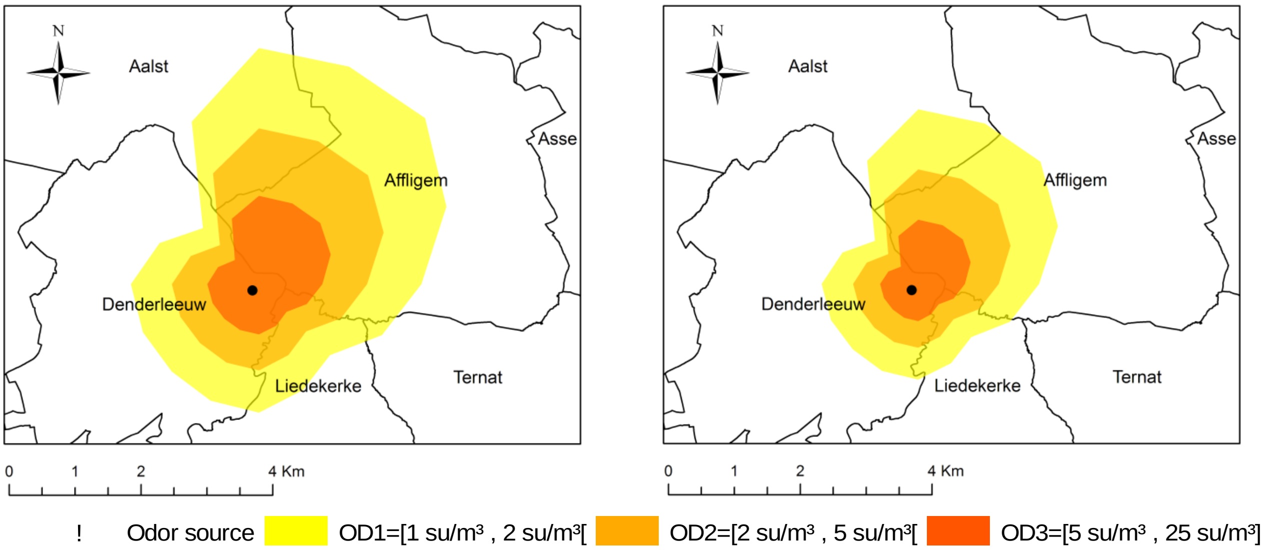

Figure 6: Location of properties

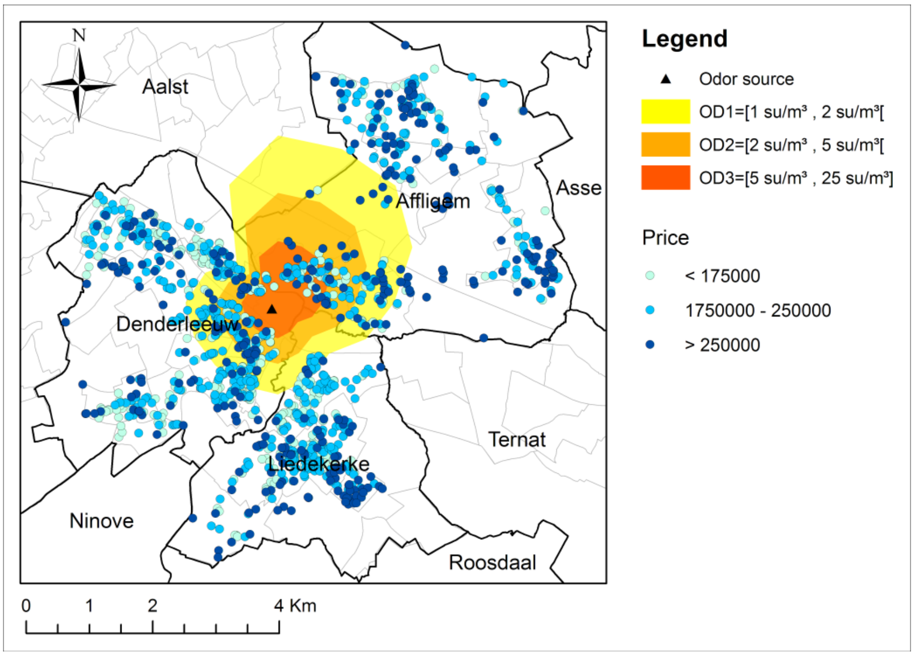

Table 6: OLS regressions

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
age	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
age squared	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
renovated	0.061**	0.061**	0.060**	0.061**	0.061**	0.065**
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.030)
rooms	0.018**	0.017**	0.017**	0.018**	0.018**	0.020***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)
garages	0.034**	0.035**	0.034**	0.034**	0.033**	0.036**
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.017)
bathrooms	0.060***	0.059***	0.058***	0.059***	0.059***	0.054**
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)
central heating	0.031	0.033	0.031	0.033	0.031	0.024
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)
garden	0.073***	0.068**	0.070**	0.069**	0.069**	0.061**
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.028)
house size	0.044	0.049*	0.043	0.048*	0.045	0.031
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.030)
lot size	0.012***	0.012***	0.012***	0.012***	0.012***	0.012***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
public	-0.198***	-0.199***	-0.201***	-0.196***	-0.196***	-0.217***
	(0.038)	(0.037)	(0.037)	(0.037)	(0.037)	(0.038)
ln(property tax basis)	0.410***	0.405***	0.416***	0.406***	0.410***	0.430***
	(0.042)	(0.042)	(0.042)	(0.042)	(0.042)	(0.045)
2004	-0.411***	-0.417***	-0.418***	-0.418***	-0.419***	-0.436***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.027)
2005	-0.253***	-0.255***	-0.256***	-0.257***	-0.258***	-0.261***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.025)
2006	-0.137***	-0.137***	-0.136***	-0.134***	-0.133***	-0.137***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.024)
2007	-0.057**	-0.056**	-0.056**	-0.055**	-0.054**	-0.055**
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.024)
distance highway exit	-0.023**	-0.015	-0.019*	-0.015	-0.017*	-0.030**
	(0.011)	(0.010)	(0.010)	(0.010)	(0.010)	(0.012)
share Belgians	0.988	1.223**	1.291**	1.095*	1.034*	0.831
	(0.636)	(0.600)	(0.593)	(0.606)	(0.609)	(0.644)
municipality Affligem	0.001	0.043*	0.030	0.042*	0.039	0.015
	(0.027)	(0.024)	(0.023)	(0.024)	(0.024)	(0.027)
municipality Liedekerke	0.031*	0.036*	0.028	0.036**	0.032*	0.021
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.021)
distance odor source	0.021**					
	(0.009)					
OD1		0.028				
		(0.022)				
OD2		-0.050**				
		(0.025)				
OD3		-0.122***				
		(0.036)				
OD			-0.079***			
			(0.021)			
odor				-0.013***	-0.022**	
				(0.004)	(0.010)	
odor squared					0.001	
					(0.001)	
ln(odor)						-0.030***
						(0.010)
constant	8.377***	8.201***	8.093***	8.326***	8.374***	8.460***
	(0.671)	(0.650)	(0.642)	(0.654)	(0.656)	(0.686)
F	133.112	123.131	134.365	133.755	127.710	117.226
R^2	0.667	0.670	0.669	0.668	0.668	0.671
adjusted R^2	0.662	0.664	0.664	0.663	0.663	0.665
N	1420	1420	1420	1420	1420	1231

Significance levels: * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

Table 7: Spatial regressions

Variable	model 1	model 2	model 3	model 4	model 5	model 6
age	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
age squared	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
renovation	0.058**	0.06**	0.058**	0.059**	0.059**	0.061**
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.030)
rooms	0.018***	0.017**	0.018**	0.018**	0.018***	0.02***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
garage	0.034**	0.034**	0.033**	0.034**	0.033**	0.035**
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.017)
bathroom	0.058***	0.058***	0.057***	0.058***	0.058***	0.052**
	(0.021)	(0.020)	(0.021)	(0.021)	(0.021)	(0.022)
central heating	0.031	0.033	0.032	0.033	0.032	0.025
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)
garden	0.073***	0.069***	0.071***	0.07***	0.07***	0.061**
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.028)
house size	0.044	0.048*	0.043	0.047*	0.045	0.030
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.030)
lot size	0.012***	0.012***	0.012***	0.012***	0.012***	0.012***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
public sale	-0.198***	-0.199***	-0.201***	-0.196***	-0.196***	-0.217***
	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)	(0.038)
ln(property tax basis)	0.411***	0.406***	0.416***	0.406***	0.41***	0.431***
	(0.043)	(0.042)	(0.042)	(0.042)	(0.042)	(0.045)
2004	-0.415***	-0.42***	-0.421***	-0.421***	-0.422***	-0.44***
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.027)
2005	-0.257***	-0.258***	-0.26***	-0.26***	-0.261***	-0.266***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.025)
2006	-0.138***	-0.138***	-0.137***	-0.135***	-0.135***	-0.139***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.024)
2007	-0.055**	-0.055**	-0.055**	-0.054**	-0.054**	-0.054**
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.024)
distance highway exit	-0.024**	-0.015	-0.019*	-0.015	-0.017	-0.031**
	(0.012)	(0.010)	(0.011)	(0.010)	(0.011)	(0.013)
share Belgians	0.992	1.229**	1.29**	1.111*	1.045*	0.817
	(0.671)	(0.616)	(0.621)	(0.632)	(0.636)	(0.670)
municipality Affligem	-0.002	0.043*	0.03	0.043*	0.039	0.015
	(0.030)	(0.025)	(0.026)	(0.026)	(0.026)	(0.029)
municipality Liedekerke	0.03	-0.008	-0.003	-0.007	-0.009	0.005
	(0.021)	(0.020)	(0.020)	(0.019)	(0.020)	(0.023)
distance odor source	0.023**					
	(0.010)					
OD1		0.026				
		(0.023)				
OD2		-0.053**				
		(0.026)				
OD3		-0.123***				
		(0.037)				
OD			-0.081***			
			(0.022)			
odor				-0.013***	-0.023**	
				(0.004)	(0.011)	
odor squared					0.001	
					(0.001)	
ln(odor)						-0.03***
						(0.010)
constant	8.523***	8.388***	8.268***	8.501***	8.555***	8.648***
	(0.738)	(0.698)	(0.700)	(0.710)	(0.713)	(0.743)
ρ (SAR)	-0.013	-0.013	-0.012	-0.013	-0.013	-0.014
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
λ (SEM)	0.327	0.155	0.268	0.239	0.247	0.264
	(0.231)	(0.251)	(0.237)	(0.239)	(0.238)	(0.237)
log likelihood	-103.96	-97.88	-99.89	-102.16	-101.65	-70.64
wald test of ρ=0	0.37	0.36	0.31	0.34	0.35	0.42
wald test of λ=0	2.00	0.38	1.28	1.00	1.07	1.24
observations	1420	1420	1420	1420	1420	1231