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Document de travail

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The Impact of Hazardous Industrial Facilities on Housing Prices: A Comparison of Parametric and Semiparametric Hedonic Price Models

Abstract

Households' willingness to pay for prevention against industrial risks can be revealed by real estate markets. With highly detailed microdata, we study housing prices in the vicinity of hazardous industries located near three important French cities (Bordeaux, Dunkirk and Rouen). We show that the impact of hazardous plants on housing values strongly differs among the three studied areas, even if they all surround chemical and petrochemical industries. We compare the results from standard parametric hedonic property models and from a more flexible, semiparametric hedonic property model. We show that the parametric model may structurally lead to an important bias in the estimated value of the impact of hazardous plants on housing values and in its variations with respect to distance to the plants.

Keywords: hedonic analysis, locally-weighted regression, urban housing markets, industrial risk

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L'impact des industries à risques sur le prix des logements : comparaison de modèles paramétriques et semi-paramétriques de prix hédoniques

Résumé

Le consentement à payer des populations pour des mesures de prévention contre les risques industriels peut être révélé par les marchés immobiliers. Avec une base de données microéconomiques très détaillées, nous étudions les prix des logements à proximité d'industries dangereuses situées près de trois grandes villes françaises (Bordeaux, Dunkerque et Rouen). Nous montrons que l'impact des usines dangereuses sur le prix des logements varie beaucoup entre les trois zones étudiées, même si elles sont toutes à proximité d'industries chimiques et pétrochimiques. Nous comparons les résultats d'un modèle paramétrique standard de prix hédoniques et ceux d'un modèle de prix hédoniques semi-paramétrique, plus flexible. Nous montrons que le modèle paramétrique peut structurellement conduire à un biais important dans la valeur estimée de l'impact des usines dangereuses sur le prix des logements et dans ses variations en fonction de la distance aux usines.

Mots-clés : analyse hédonique, régression localement pondérée, marchés du logement urbains, risque industriel

Classification JEL : C21, Q51, R52, R21

1 Introduction

Real estate markets can reveal households' willingness to pay to reduce their exposure to hazardous industrial facilities. Clearly, hazardous industrial activities generate strong externalities, many of them being negative. Indeed, neighboring populations partly bear the cost of a potential industrial accident,[1] and may endure day-to-day nuisances associated with the ordinary course of activity. However, these facilities also generate positive externalities (Greenstone et al., 2010), potentially more diffuse: they provide, directly and indirectly, employment; through local taxes, they may contribute to the economic development of the municipalities. Declining the impact of distance to hazardous facilities on housing values with respect to their activities reveals in which extent these activities are perceived as disamenities. We estimate the impact of distance to hazardous plants on housing values by using hedonic price models. The first-order derivative of the hedonic price function with respect to the distance to hazardous plants provides an estimate of the implicit price of the distance to these plants, that is an estimate of the buyers' willingness to pay to live far from these plants. We study housing prices in the vicinity of three important French cities (Bordeaux, Dunkirk and Rouen). These three chosen industrial areas all include chemical and petrochemical industries, but with different socioeconomic characteristics of their neighborhoods and different perceptions of industrial risks.[2]

Our first contribution is to study the impact of hazardous chemical and petrochemical industries on housing prices with highly detailed microdata. Our unique database is much richer than the ones used for studies relative to the impact of similar industrial risks on housing prices. Impact of risk exposure on real estate prices is estimated for oil facilities by Boxall et al. (2005) and Flower and Ragas (1994), for chemical industry by Carroll et al. (1996), and for industrial areas with chemical or petrochemical facilities by Sauvage (1997) and Travers et al. (2009). These studies use data with few (or without) extrinsic characteristics of the dwellings and without information on buyers and sellers.[3] Our

[1] Damages certainly imply the liability of the industrialist, but compensation can be delayed and remain partial. In particular, some physical and moral damages cannot be repaired.

[2] The industrial areas near Bordeaux and Rouen have become sadly well-known after our data collection. In the gunpowder near Bordeaux, a fire caused one death and two seriously injured persons in December 2013 ("Gironde : un mort et deux blessés dans un incendie sur un site classé Seveso" by Jean-Pierre Tamisier, December 6th, 2013, *Sud-Ouest*). Near Rouen, mercaptan gas escape from one of the factories, the Lubrizol company, caused foul odor in France and in England in January 2013 ("Foul-Smelling Cloud Drifts Over France, Alarming Residents" by Scott Sayare, January 22nd, 2013, *The New York Times*).

[3] See Table 13 in Appendix A.2 for a review of all these studies and their data. The impact on housing prices of other industrial activities has been studied, in particular the impact of power plants (Davis, 2011), waste treatment and storage (Greenstone and Gallagher (2008), see Farber (1998) for a review) and of natural gas (Boxall et al., 2005). Air pollution also significantly decreases housing prices (Chay and

case study relies on a detailed dwelling-level micro-database, each dwelling's address being precisely geocoded. Detailed data relative to their extrinsic characteristics have been collected: proximity to central business district, shops and public utilities, exposure to industrial risk, to other risks or pollutions. Dwellings' price and intrinsic characteristics come from notarial data; information about buyers and sellers is also provided.

Our second contribution consists in comparing the impacts of distance to hazardous plants on housing prices, as estimated by two models: a standard parametric model and a semiparametric model. The semiparametric regression is a locally weighted regression that allows implicit prices to vary with respect to space, time of sale and buyer's characteristics, while keeping some smoothness in their distribution.[4] It enables to relax and to test the assumption of fixed parameters, that is of constant implicit prices across space, time and among buyers. The fixed-parameter assumption is rejected, which confirms the need for flexible forms and pleads for the use of semiparametric models. Such a comparison of parametric and semiparametric models had not been performed until now in the analysis of industrial risks, but for other amenities, such as agricultural pollution on housing prices (Bontemps et al., 2008), light rail access (Redfearn, 2009); all these analyses plead for the use of semiparametric models. Anglin and Gencay (1996) also show that semiparametric hedonic models outperform parametric ones. McMillen (2010), McMillen and Redfearn (2010), Redfearn (2009), Sunding and Swoboda (2010) specifically compare parametric models with locally weighted regression and recommend the use of this semiparametric model. Redfearn (2009) shows that implicit prices vary spatially and temporally and that assuming fixed implicit prices is a misspecification of hedonic model. This misuse of parametric models has important consequences in our case study. If signs and orders of magnitude of effects are similar in the two models for the very wide majority of coefficients, the estimated impacts of the distance to highly hazardous plants on housing prices significantly differ between the two models. The parametric model leads to an important bias (here an overestimation) in the estimated value of this impact near Bordeaux and Rouen and in its variations with respect to distance to the plants near Rouen.

Using the semiparametric model, we show that the impact of hazardous plants on housing values strongly differs among the three studied industrial areas, even if they all surround

Greenstone (2005), see Maslianskaïa-Pautrel (2008) for a review).

[4] Locally weighted regressions have already been applied in several works by the French National Institute of Statistics and Economics Studies (INSEE). See Floch (2012) for examples and a methodological presentation of this model in French.

chemical and petrochemical industries. The gunpowder factory near Bordeaux is a former military plant, not necessarily perceived as hazardous by neighboring population. We find that its proximity is even valued in its very close vicinity, probably because its neighborhoods are green and very quiet places. Thus, we capture here unobserved amenities which are spatially correlated with the distance to the plant. Near Dunkirk and Rouen, chemical activities are clearly identified as hazardous by local populations. However, near Dunkirk, we find no significant impact of the distance to highly hazardous plants on housing prices, likely because these industrial risks are overshadowed by the nuclear plant in Gravelines (located 18 km from Dunkirk). Near Rouen, highly hazardous plants are perceived as disamenities: on average, households are willing to pay around 1.2% of their dwelling price to go 100 more meters away from these plants. This marginal willingness to pay decreases with respect to the distance to the plants, as marginal gains (in terms of exposure reduction) of going further away from the hazard source are likely to decrease. Finally, we show that this marginal willingness to pay increases over time following the AZF accident, information policies, or the implementation of the technological disasters insurance system.

Our findings have important implications. Inasmuch as households are aware of the differences in amenities across locations,[5] the impact of distance to highly hazardous plants on housing prices can be interpreted as the local populations' marginal willingness to pay for prevention against industrial risks. This willingness is used in cost-benefit analyses that estimate the efficient level of prevention against industrial risks for the civil society (see Treich (2005) for a review). The benefits, which correspond to the population's willingness to pay for this reduction, are often revealed by real estate markets.[6] Most of the time this willingness to pay is estimated by parametric hedonic models and for similar types of industrial activities, over a potentially different study area or period. Our results show that parametric hedonic models can lead to an important bias in the estimated value of the marginal willingness to pay. Besides, our results show that estimated willingness to pay for prevention has a limited external validity: it strongly differs among industrial areas, even among chemical and petrochemical industries; it also depends on the distance

[5] Currie et al. (2013)'s findings do not contradict perfect, or at least unbiased, information about industrial hazardous activities in the housing market, even in the presence of scientific uncertainty about health risks.

[6] The benefits are the monetary value of the reduction of risk exposure, that is the population's willingness to pay for this reduction. This willingness to pay can be assessed either by stated or revealed preference methods. The stated preference method comes up against numerous biases in the questionnaire of so called contingent valuation studies and the limited incentives of questioned households to reveal their preferences. The revealed preference method consists in observing actual individual decisions on markets, such as real estate market.

to these facilities and on time. Thus, our findings plead for a careful use of population's willingness to pay for prevention against industrial risks in the cost-benefit analyses of prevention measures, as it can lead to a significant bias in the estimation of the efficient prevention level.

The paper is organized as follows. The parametric and semiparametric models are presented in Section 2. Section 3 describes the three industrial areas, the delimitation of study areas and the data. Section 4 exposes and compares the results get from parametric and semiparametric models. Section 5 concludes.

2 Model

Hedonic property models. Real estate markets can reveal households' willingness to pay to reduce their exposure to hazardous industrial facilities. Hedonic property models enable to estimate the implicit price of the distance to highly hazardous plants (which is the first-order derivative of price with respect to the distance to highly hazardous plants). This implicit price is equal to the households' (buyers' or sellers') marginal willingness to go one more meter away from these plants. Indeed, in the framework formalized by Rosen (1974), a dwelling is defined by its distance d to highly hazardous plants and several other characteristics X, which determine its price $P(d, X)$. When choosing their location, households equalize their marginal willingness to pay for increasing each characteristic by one unit with the marginal, or implicit, price of this characteristic.[7] Thus, estimation of the hedonic price function provides an estimation of the implicit price of the distance d to highly hazardous plants $\partial P(d, X)/\partial d$, which can so be interpreted as households' marginal willingness to pay to go one more meter away from highly hazardous plants.

Unless making very specific assumptions, the hedonic price function is not linear and has no known explicit form (see Freeman (2003) for a review of hedonic price methods). This is the reason why we have first performed many parametric models: linear, log-linear, log-log and linear with Box-Cox transformations of the price and continuous regressors - while

[7] Formally, a household of income y chooses his location by maximizing his utility $U(z, d, X)$, where z denotes the amount of composite consumer good (which includes all consumer goods except land), under his budget constraint $y = z + P(d, X)$. Location choices by households maximize their utility by equalizing their marginal rate of substitution between each characteristic (d or x_k) and money with the implicit price ($\partial P(d, X)/\partial d$ or $\partial P(d, X)/\partial x_k$):

$$\frac{U_d(z, d, X)}{U_z(z, d, X)} = \frac{\partial P(d, X)}{\partial d}, \quad \forall k, \frac{U_{x_k}(z, d, X)}{U_z(z, d, X)} = \frac{\partial P(d, X)}{\partial x_k}. \tag{1}$$

allowing these Box-Cox coefficients to be different (Grislain-Letrémy and Katossky, 2013). For each of these specifications, we have either added fixed effects (municipality dummies) and tested for different types of spatial dependency (spatial errors and/or spatial lag). Comparison by likelihood ratio tests of these nested models shows that a more flexible form is indeed better (Grislain-Letrémy and Katossky, 2013).

In addition to the baseline log-linear model, we present here two extensions of this model: a parametric model and a semiparametric one.

2.1 Parametric model

The parametric model is a log-polynomial model with municipality and time dummies based on ordinary least squares. We estimate the logarithm of the price P_i of dwelling i as a function of the distance to the plants d_i, the dwelling's other characteristics X_i and the vector η_{t_i} of time dummies (for month and year of sale). Near Bordeaux, the square and the cube of the distance to highly hazardous plants are significant and included in the regression. Near Rouen, only the square of the distance to highly hazardous plants is significant and included in the regression.

$$\text{OLS Bordeaux:}\quad \ln P_i = \alpha + \beta_1 d_i + \beta_2 d_i^2 + \beta_3 d_i^3 + \gamma' X_i + \tau' \eta_{t_i}, \tag{2}$$

$$\text{OLS Dunkirk:}\quad \ln P_i = \alpha + \beta_1 d_i + \gamma' X_i + \tau' \eta_{t_i}, \tag{3}$$

$$\text{OLS Rouen:}\quad \ln P_i = \alpha + \beta_1 d_i + \beta_2 d_i^2 + \gamma' X_i + \tau' \eta_{t_i}. \tag{4}$$

2.2 Semiparametric model

Motivation. The semiparametric model is also based on a log-linear specification. It is a locally weighted regression (LWR), which allows the marginal willingnesses to pay for characteristics to vary with respect to space, time of sale and buyer's characteristics, while keeping some smoothness in their distribution. Indeed, the marginal willingness to pay for each characteristic is *a priori* not uniform over the study area (McMillen, 2010). It may also vary after events that could have changed risk perception, such as local or national accidents, information policies. Indeed, several empirical works show that real estate prices can be significantly modified by information policies,[8] or insurance coverage.[9] Finally, this

[8] See Gayer et al. (2000) and Kohlhase (1991) in the case of hazardous waste facilities and Maani (1991) in the case of high-pressure gas pipeline. However, in the case of airport noise disclosure, Pope (2008) shows that publicly available information may not be adequately considered by all buyers.

[9] For example, flood insurance shapes real estate prices (MacDonald et al. (1990), Harrison et al. (2001), Morgan (2007) and Bin et al. (2008)).

willingness to pay may vary among buyers, because of heterogenous preferences.[10]

McMillen (2010), McMillen and Redfearn (2010), Redfearn (2009), Sunding and Swoboda (2010) specifically compare parametric models with locally weighted regression and plead for the use of this semiparametric model. Redfearn (2009) provides two main reasons that plead for the use of locally weighted regression instead of standard hedonic models: the rejected standard assumption of fixed implicit prices and the presence of omitted local amenities. First, Redfearn (2009)'s results show that the standard assumption of fixed implicit prices is rejected and suggest that imposing fixed parameters generates spatial patterns in the errors that leads to parameter estimates highly sensitive to very small changes in sample or in specification. Second, Redfearn (2009) compares regressions with and without a known local amenity and shows that the local regression analysis appears more robust to omitted local amenities.

Locally weighted regression: formalization. We estimate the logarithm of the price P_i of dwelling i as a function of the distance to the plants d_i, the dwelling's other characteristics X_i and the vector η_{t_i} of dummies for time of sale. We allow the coefficients to vary with respect to space (x and y coordinates, xc_i and yc_i), time of sale (t_i) and buyer's income (y_i), while keeping some smoothness in their distribution. We choose here the income as the main buyer's characteristic. Indeed, income is imputed using gender, age, marital status and municipality of origin (Section 3) and it summarizes this way the main observed buyer's characteristics.[11] By denoting $Z_i = (xc_i, yc_i, t_i, y_i)$, we get

$$\text{LWR:}\quad \ln P_i = \alpha(Z_i) + \beta(Z_i)d_i + \gamma'(Z_i)X_i + \tau'(Z_i)\eta_{t_i}. \tag{5}$$

More precisely, locally weighted regression is a set of weighted least square regressions, with one regression for each observation (see McMillen and Redfearn (2010) for a review). Each regression estimates the implicit prices at each observation using a subsample of "close" observations. Proximity refers here to spatial proximity, temporal proximity, as well as buyer's characteristics proximity. The set of observations used in each local regression corresponds to the observations within a window around the considered observation

[10] Proximity in terms of preferences may be already partly captured by geographical proximity, because of a sorting on housing market.

[11] We could have also allowed the marginal willingnesses to pay for characteristics to vary with respect to other characteristics of buyers, but the results get from parametric models provide very little hope in this direction. Indeed, in several parametric models we did not get significant coefficients when the distance to the plant was crossed with other characteristics of buyers.

j.[12] Formally, the objective function for estimation of locally weighted regression is, for observation j:

$$\text{LWR:} \quad \sum_{i=1}^{n} (\ln P_i - \alpha - \beta d_i - \gamma' X_i - \tau' \eta_{t_i})^2 W_{ij}, \tag{6}$$

where $W_{ij} = f(Z_i, Z_j)$ is the weight for each observation i; this weight is a decreasing function of the spatial, temporal and buyer's distance from observation i to the considered observation j.

Weights. First, we apply the Mahalanobis distance $d^M(Z_i, Z_j)$ between Z_i and Z_j to go from four dimensions to one dimension in our kernel:[13]

$$d^M(Z_i, Z_j) = \sqrt{(Z_i - Z_j)^T (cov(Z))^{-1} (Z_i - Z_j)}, \tag{7}$$

where $Z = (Z_1, ..., Z_n)$. Then, weights are generated by a kernel weighting function, here the tri-cubic kernel weighting function, applied to this distance:

$$W_{ij} = \left(1 - \left(\frac{d^M(Z_i, Z_j)}{d^M_{max}(Z_i, Z_j)}\right)^3\right)^3, \tag{8}$$

where $d^M_{max}(Z_i, Z_j)$ is the largest Mahalanobis distance from the considered observation j to any observation within the window.

Window. If the choice of the kernel function has a limited impact on the estimation results (McMillen, 2010),[14] the choice of the window is crucial. The common window for all regressions can be chosen as a minimizer of the mean difference between the dependent variable and the estimated value over all regressions when excluding the considered observation from the sample.[15] The size of the window estimated by cross-validation corre-

[12] Estimating numerous separate regressions for each observation may lead to think that a high degree of freedom is here used. This is not the case because of the smoothness implied by overlapping samples (Redfearn (2009), see McMillen and Redfearn (2010) for more details).

[13] Compared to the Euclidean distance, the Mahalanobis distance takes into account the correlations of the data set and is scale-invariant.

[14] Results are robust when using a gaussian kernel function instead of a tri-cubic one.

[15] The LWR model can be written under a linear form (McMillen and Redfearn, 2010). By denoting $Y_i = \ln(P_i)$, we get

$$Y_i = LY_i + u_i. \tag{9}$$

Thus, a cross-validation estimate of h is a minimizer of the cross-validation measure $CV(h)$:

$$CV(h) = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{Y_i - \hat{Y}_{h,i}}{1 - l_{ii}}\right)^2, \tag{10}$$

sponds to 36% of the initial sample near Bordeaux, 40% near Dunkirk, 76% near Rouen.[16] However, larger windows are needed when the objective is to measure marginal effects and not to predict the dependent variable (McMillen, 2010). This is the reason why we use windows that correspond to 80% of the initial sample in the three studied cases.[17]

Thus, locally weighted regression allows coefficients to vary with space, time of sale and buyer's characteristics, while keeping some smoothness in their distribution (implied by overlapping samples). This is why this model enables to relax and to test the assumption of fixed parameters, that is of constant implicit prices across space, time and among buyers. Locally weighted regressions have already been used in several works by INSEE. Floch (2012) provides examples of these works and a methodological presentation of this model in French.

3 Industrial areas, study areas and data

We have realized an important work of data collection. We detail here the selection of industrial areas, the delimitation of study areas and the collected variables.

3.1 Industrial areas

Many French hazardous industrial plants are surrounded by a high population density and could so be considered for this analysis. However, the important work of data collection limits the number of sites that could be studied. The three industrial areas are chosen for the different socioeconomic characteristics of their neighborhood and for their different perceptions of industrial risks.

Socioeconomic characteristics. The three industrial areas studied are located near important French cities: Bordeaux, Dunkirk and Rouen. The three industrial areas present different socioeconomic characteristics (Table 1). Neighborhoods of the gunpowder near Bordeaux are the richest ones; many inhabitants are executives in the aerospace indus-

where $\hat{Y}_{h,i}$ is the estimate based on the sample from which observation i is removed and using a window of size h around i.

[16] Initial samples include 1,423 observations near Bordeaux, 1,016 near Dunkirk and 571 near Rouen. Thus, the size of the window estimated by cross-validation corresponds to 512 observations near Bordeaux, 406 near Dunkirk and 434 near Rouen.

[17] Here larger windows are all the more needed, as the interest variable (the distance to highly hazardous plants) varies with some kernel variables (the geographic coordinates): small windows may lead to imprecise estimates of its marginal effect. However, when considering smaller windows (60%, 40%) with either tri-cubic or gaussian kernels, the significance and the mean value of the impact of our interest variable on dwelling value appear as robust.

try. Dunkirk and its neighborhoods are the densest area; many households are workers. Neighborhoods near Rouen are in an intermediate position between the first two areas: income is higher than near Dunkirk and lower than near Bordeaux; many inhabitants are executives and work far from their home. In the three areas, according to the 2008 French annual declaration of social data, at the most 2% of the population in each municipality is employed by the highly hazardous plants that are described below.

Table 1: Population's socioeconomic characteristics in the three studied cases

Municipality	INSEE code	Population (a)	Population density (a) (per sq km)	Percentage of built area (b)	Average tax revenue (a) (euro)	Sports and sociocultural facilities (c)	Distance to labor pool (d) (km)
Near Bordeaux							
Le Haillan	33200	8,378	904	8	26,817	14	5.9
Martignas-sur-Jalles	33273	6,633	251	2	29,005	27	9.2
Mérignac	33281	65,469	1,359	9	23,181	72	4.4
Saint-Aubin-de-Médoc	33376	5,550	159	1	41,577	12	11.1
Saint-Médard-en-Jalles	33449	26,984	315	3	27,599	48	4.8
Le Taillan-Médoc	33519	8,668	571	5	30,412	14	4.9
Near Dunkirk							
Coudekerque-Branche	59155	22,994	2,515	11	18,641	23	4.3
Dunkirk	59183	69,274	1,855	12	20,218	18	4.1
Fort-Mardyck	59248	3,586	2,543	13	18,610	7	9
Saint-Pol-sur-Mer	59540	22,100	4,299	16	14,711	14	6.2
Near Rouen							
Grand-Couronne	76319	9,346	552	5	20,083	18	20.5
Hautot-sur-Seine	76350	9,346	160	1	26,423	2	19.3
Moulineaux	76457	881	238	2	21,287	10	20.6
Petit-Couronne	76497	8,690	679	5	19,638	28	21.1
Sahurs	76550	1,310	117	1	27,017	5	26.8
Val-de-la-Haye	76717	751	74	1	23,673	5	20.5

Note: Fort-Mardyck and Saint-Pol-sur-Mer municipalities have been associated to Dunkirk municipality in 2010.
Sources: (a) INSEE, (b) building database of the Geographical National Institute, (c) topology database of the Geographical National Institute, (d) Sitranet.

Risks and perceptions of industrial activities. Official classification of hazardous plants is defined by regulation. The Seveso II Directive (Council directive 96/82/EC on the control of major-accident hazards) defines hazardous industries according to the presence of hazardous substances or preparations. The degree of hazard is defined with respect to nature and quantities of substances. Two categories of hazardous facilities are so defined: "upper tier" sites and "lower tier" sites. The French legislation is actually harsher than the European one: the French classification includes many other far less hazardous sites, called "authorized" plants.

The three industrial areas here studied all include hazardous chemical and petrochemical industries. However they present different industrial activities and very different perceptions of associated risks by local populations. The gunpowder factory near Bordeaux was settled in 1660.[18] Today, it comprises two "upper tier" sites of the Seveso II Directive. By manufacturing gunpowder and explosives, the factory mainly exposes local population to a risk of explosion. However, it is not necessarily perceived as hazardous by neighboring population. Indeed, it is a former military plant; only barbed wire can be seen from some places of the neighborhoods. Furthermore, as the plant is wide (650 buildings over 350 hectares), risk is relatively "contained" within the industrial site. The only nuisance associated to the plant is the transportation of hazardous materials on a precise and limited route.

On the contrary, chemical activities near Dunkirk or Rouen are clearly identified as hazardous by local populations. Near Dunkirk, these activities appeared in the 1970s.[19] There are now sixteen hazardous plants: fourteen "upper tier" Seveso sites, two authorized. Their activities consist in storage and refining of oil products, metallurgy, manufacture of industrial gases, of chemical and pharmaceutical products and waste treatment. They expose local population to risks of explosion, fire and toxic impacts. The plants (either buildings, chimneys or at least plumes of smoke) can be seen from every neighboring dwelling. However, the presence of a nuclear plant in Gravelines (18 km from Dunkirk) may overshadow the exposure to these industrial risks.

Near Rouen, chemical activities appeared between the 1960s and the 1990s.[20] There are now thirteen hazardous plants: two "upper tier" Seveso sites , one "lower tier" Seveso site, ten authorized. Their activities are quite diverse: storage and refining of liquid petroleum gas, production of Diester oil (biodiesel) and of liquid carbon dioxide, perfumes storage, paper manufacture, goods transportation and warehouses. They expose local population to the same risks than near Dunkirk: explosion, fire, toxic impacts. However, because of landscape chimneys or silos cannot be seen from some neighboring dwellings.

Although all these highly hazardous plants were established well before the study period, several other events, either local or national, may have modified risk perception during this

[18] Municipalities in the neighborhoods were initially developed thanks to the activity of the gunpowder. Urban development was then explained by attraction to Bordeaux center.

[19] Near Dunkirk, after World War II, urbanization was realized around industrial activities which were not perceived as hazardous (shipyards, steel industry); hazardous plants (chemistry, petrochemistry) appeared in Dunkirk harbor only in the 1970s.

[20] Near Rouen, few plants established in the 1920s and 1930s; the majority of plants progressively appeared between the 1960s and the 1990s and cities get closer and closer to these different plants.

period, that is between 2000 and 2008. We detail here all these local and national events (Table 2). Local events are accidents and local policies. Only one accident happened on January 12, 2007 at Rubis Terminal (storage of liquid flammable and agrochemical products) near Dunkirk.[21] Local policies include the distribution of information leaflets, the update of the emergency plan for households and the implementation of local committees for information and consultation.[22] National events are the AZF accident in 2001 in Toulouse and implementation of laws during the study period. The raise of public awareness of industrial dangers following the AZF accident could have been all the more important near Rouen that one of the studied plants, Grande Paroisse Normandy, has a very similar activity to the AZF plant and belongs to the same company, Grande Paroisse (a subsidiary of Total group).[23] Besides, the 2003 law created the technological disasters insurance system,[24] which improves the coverage of households.[25]

3.2 Delimitation of study areas

In order to measure the impact of distance to plants on housing values, the study area has to be broad enough to include dwellings close and far from the plants. However, as Redfearn (2009) notes, "expanding the geographic scope of the sample is likely to draw additional omitted amenities and/or more submarkets". Indeed, in order to limit the number of collected characteristics of the dwellings and to avoid districts in which neighborhood quality is difficult to capture, the central business district and few atypical districts, cor-

[21] Neighboring populations saw flames and plumes of smoke. The accident triggered an emergency plan inside the plant and required the intervention of civil fire brigades. After the study period, other accidents occurred. In the gunpowder near Bordeaux, a fire caused one death and two seriously injured persons in December 2013; near Rouen, mercaptan gas escape from one of the factories, the Lubrizol company, caused foul odor in France and in England in January 2013.

[22] Some future buyers not coming from the study area may not be informed by information releases, in particular by information leaflets about the emergency plan for households. Indeed, information leaflets were distributed in 2006 near Dunkirk and in 2007 near Rouen to current owners (Table 2).

[23] Indeed, the AZF accident appears to have left a particularly deep and long-lasting impression near Rouen (""Grande-Paroisse" à Rouen, un site Seveso hanté par le spectre d'AZF" by Audrey Garric, February 5, 2013. *Le Monde.fr*).

[24] The 2003 law also created technological risk prevention plans, but they were started after the study period in each study area. In addition, the very same law created mandatory information for buyers and tenants: the seller or the landlord has to precise in writing whether his dwelling is located in an area covered by a technological (or natural) risk prevention plan. This information policy was implemented on June 1st, 2006. As technological risk prevention plans were started after the study period, no such information was released in the three studied areas.

[25] Technological disasters insurance aims to manage the basic coverage for victims by avoiding long litigation and by covering the residual risk of no responsible identification. Indeed, the guarantee against technological disasters is mandatorily included in home insurance, which is widely purchased in metropolitan France (Calvet and Grislain-Letrémy, 2011), and the coverage corresponds to the real estate of main home. Thus, technological disasters premium is included in the home insurance premium; it amounts to a few euros per year. In case of disaster, households are compensated by their home insurer, which then turns against the industrialist liable for the damages (or the industrialist's insurer).

Table 2: Local and national events that may have modified industrial risk perception during the study period (2000-2008)

Year	Bordeaux	Dunkirk	Rouen	National level
2001	-	-	-	AZF accident
2002	-	Information leaflets	-	-
2003	-	-	-	Law
2004	-	Update of the emergency plan for households	-	-
2005	-	-	Creation of local committee for information and consultation	-
2006	-	Creation of local committee for information and consultation + information leaflets about the emergency plan for households	-	
2007	-	Accident	Information leaflets about the emergency plan for households (∗)	-

Note: (∗) in all municipalities except Moulineaux.
Source: reports by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.

responding to less than 5% of the samples, are excluded.[26]

The chosen study areas include dwellings in the very close vicinity of the plants and also dwellings far from 10 km near Bordeaux, 4 km near Dunkirk and 5 km near Rouen (Table 10 in Appendix A.1 and Figures 1, 2 and 3). The literature studying the impact of similar industrial risks on housing prices uses similar study areas (Table 13 in Appendix A.2).[27]

3.3 Data collection

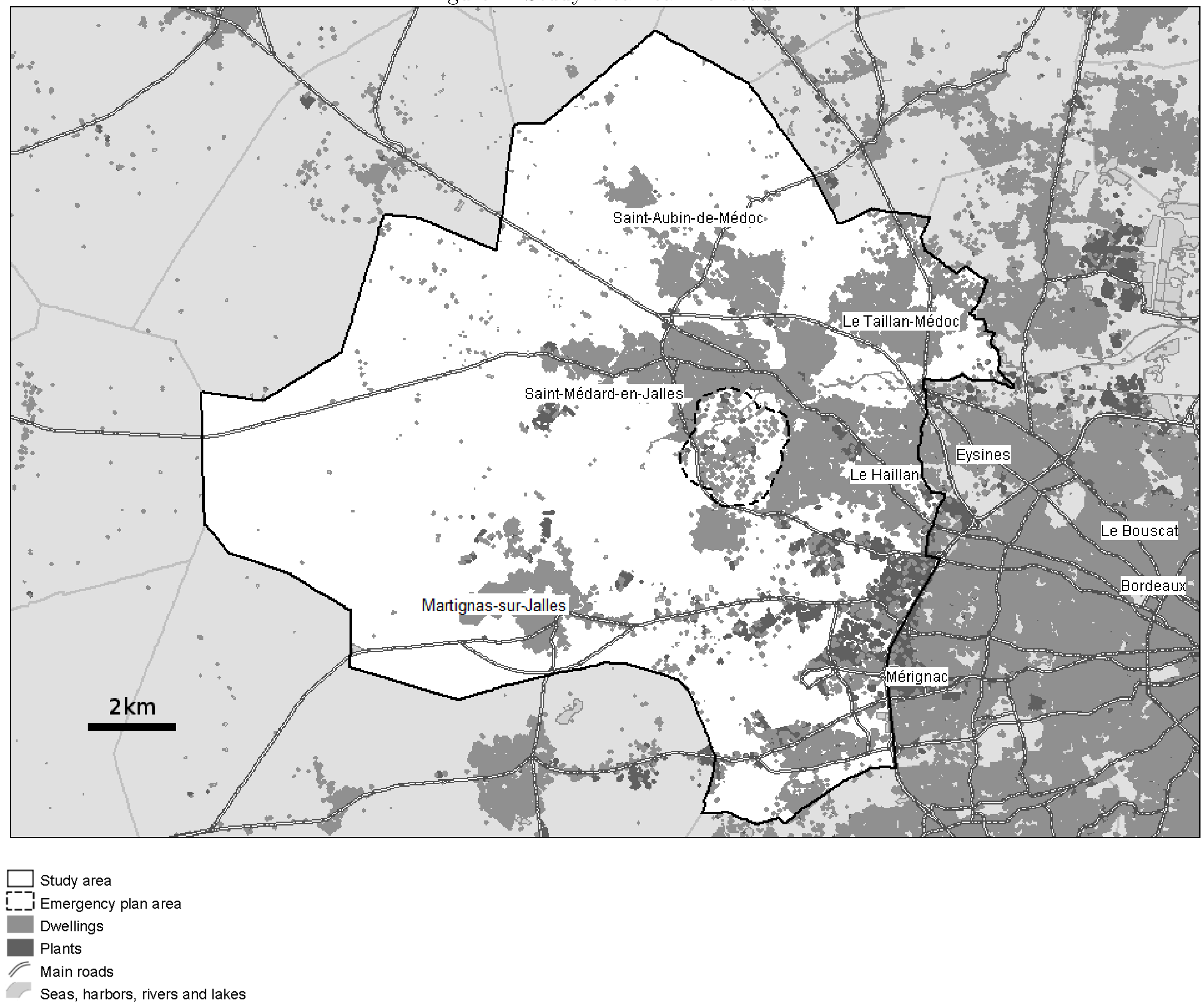
Our analysis requires data on price, characteristics of dwellings, buyers and sellers (Table 3). The price of the dwelling and its intrinsic characteristics (state, living space, number of rooms, etc.) come from PERVAL notarial data in the years 2000, 2002, 2004, 2006 and 2008. Thus, only dwelling purchases (as opposed to rentings) can be studied.[28] Besides,

[26]The selection of districts is hereafter detailed for Dunkirk, where this selection is the most important. Highly attractive districts that are Téteghem municipality (the select residential suburb of Dunkirk), the historic center and the sandbar in the East of the urban area (Dunkirk-Darses, Dunkirk-Malo-les-Bains) are excluded. Very unattractive districts such as Mardyck village and Grande Synthe municipalities are also excluded. Grande Synthe municipality is an urban renewal zone where housing prices are relatively low because of civil insecurity (petty crime, acts of violence), but this low quality of neighborhood is difficult to capture. Finally, Leffrinckoucke municipality is excluded, since the presence of a little hazardous plant but emitting a black plume of smoke can be a source of confusion for inhabitants with the other hazardous plants here studied.

[27]The two exceptions are Carroll et al. (1996), whose study area includes almost 8,000 dwellings, among which some are 35 km far from the plant, and Boxall et al. (2005), who analyze a rural area and are so led to study a wide study area to get a sufficient number of observations.

[28]Data do not specify whether buyers intend to live in their new dwelling or to rent it.

Figure 1: Study area near Bordeaux

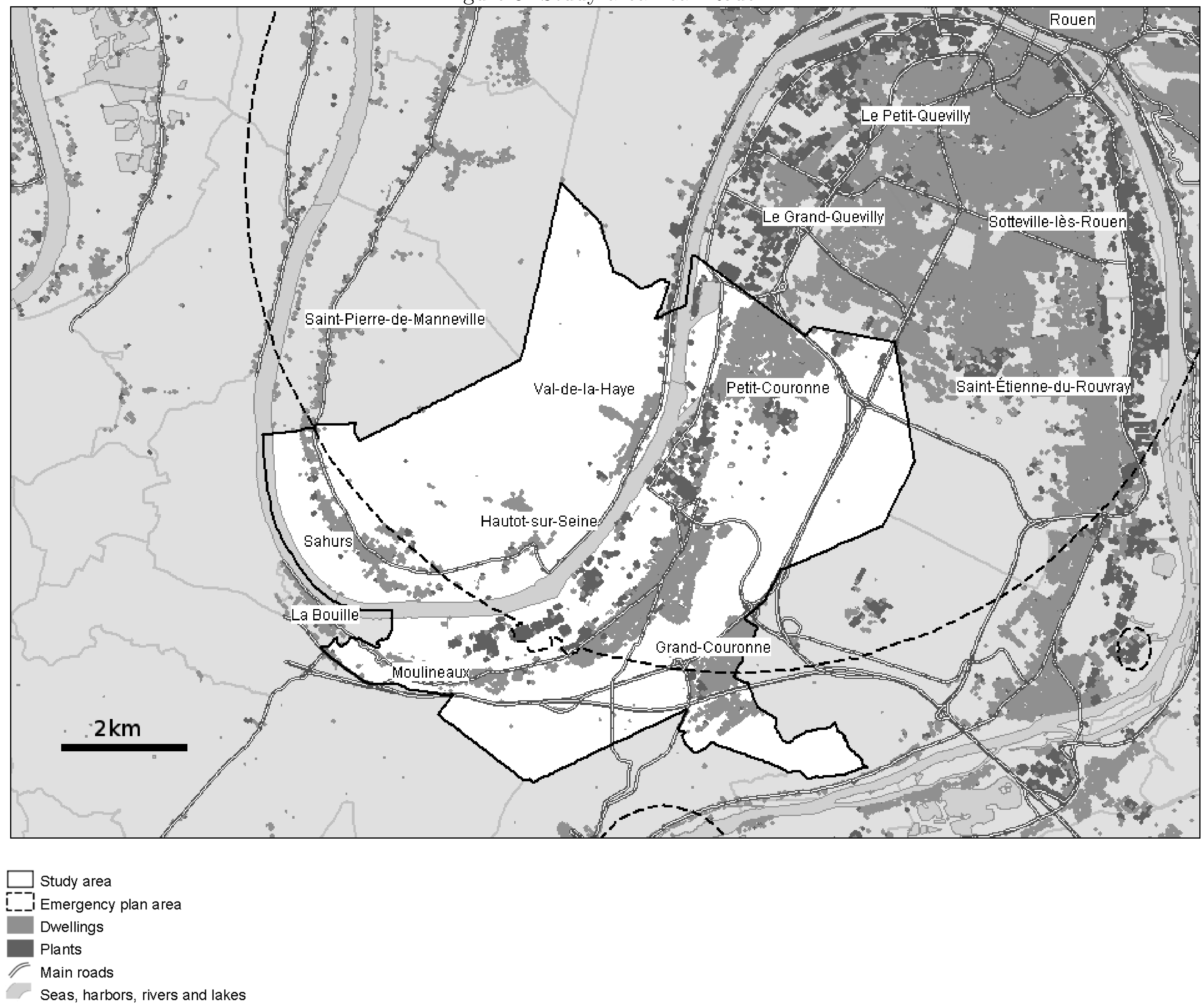


Source: base map from the topology database of National Geographic Institute, production by authors.

Figure 2: Study area near Dunkirk

Source: base map from the topology database of National Geographic Institute, production by authors.

Figure 3: Study area near Rouen



Source: base map from the topology database of National Geographic Institute, production by authors.

we consider transactions only between households. Furthermore, we restrict our analysis to houses, which represent a homogeneous market.[29] Each dwelling's address is precisely geocoded; detailed data relative to their extrinsic characteristics are collected: commuting time (by car) to central business district, distance to shops and public utilities, exposure to industrial risk, to other risks or pollutions.[30] Finally, the database from the French solicitors also provides information about buyers and sellers: their gender, their age, their social and occupational group, their marital status and their municipality of origin.[31] Annual income is allocated using statements of income from the General Directorate of Public Finances from 2004 to 2008.[32]

Thus, our database is unique and much richer than the ones used for studies relative to the impact of similar industrial risks on housing prices, which use data with few (or without) extrinsic characteristics of the dwellings and without information on buyers and sellers (Table 13 in Appendix A.2). Our samples finally include 1,423 observations near Bordeaux, 1,016 near Dunkirk and 571 near Rouen.[33] Detailed descriptive statistics are provided in Appendix A.1 (Tables 9, 10 and 11). The literature studying the impact of similar industrial risks on housing prices uses a similar number of observations (Table 13 in Appendix A.2).

Our key variable of interest is the distance from the dwelling to highly hazardous plant (mainly Seveso sites, "upper tier" and "lower tier" ones). We also consider distance to "authorized plants" (subject to the regime of classified plants for the environment protection) and location in risk management areas. These areas are the emergency planning zone for households and two areas of control for future land use: the exclusion area, called "Z1 area", corresponds to the area with lethal damages in case of accident; the area where new buildings are allowed but limited, called "Z2 area", corresponds to irreversible damages. As these zones are very limited, they include a small number of transactions during the

[29] Houses are majority in our samples: transactions include 83% of houses near Bordeaux, 87% near Dunkirk and 72% near Rouen.

[30] Geographic distance to central business district was also used and gave similar estimation results.

[31] This information is relative to the buyer (or seller) himself, or to the household reference person. Near Bordeaux, 3% of observations do not include any information on buyers (or only their municipality of origin) and are excluded from the sample. Near Dunkirk, 6% of observations do not provide the main information on buyers (gender, age, marital status) and are excluded; the social and occupational group is missing for 30% of observations. Near Rouen, 9% of observations do not include any information on buyers (or only their municipality of origin) and are excluded from the sample.

[32] Income is allocated using gender, age, marital status and municipality of origin. This leads us to exclude few foreign buyers (less than 1%) for whom we could not allocate income.

[33] In the chosen study areas, transactions within each jurisdiction are relatively uniformly distributed over the study period (Table 12 in Appendix A.1).

study period (Table 10 in Appendix A.1). Finally, as the hazardous plants near Rouen present the specificity not to be seen from some dwellings, we consider the dummy for view of plants from the dwelling near Rouen.[34]

Table 3: Data

Dwelling characteristics		
Intrinsic characteristics (a)	*Extrinsic characteristics*	
Price (including tax)	Distance and commuting time (by car) to central business district (∗)	(b) ,(f)
House or apartment		
Less than 5 years old	Distance to market square	(c), (d)
Condition	Distance to drugstore	(c), (d)
Living space (⋆)	Distance to food shop	(c), (d), (e)
Number of rooms	Distance to bus stop	(f)
Number of bathrooms	Distance to park	(f)
Number of parking lots	Distance to nursery or primary school	(e), (g)
Presence of a terrace	Distance to high school	(e), (g)
Presence of a balcony	Distance to the nearest highly hazardous plants (†)	(h)
Presence of an elevator	Distance to the nearest authorized plants (‡)	(h)
Presence of a swimming pool	View of industrial plants (near Rouen) (⋄)	(g)
Presence of a basement	Location in a land use control area (Z1, Z2)	(i)
Presence of a cellar	Location in an area of emergency plan for households	(j)
Presence of annexes	Location in an area exposed to natural hazards (▷)	(i)
Presence of outbuildings	Location in an area exposed to other hazards (▷)	(i)
Presence of an attic	Location in a residual pollution area	(k)
Area of land	Location in environmental protection area	(i)
	Location in conservation easement area	(i)
	Sound exposure to a land transport facility	(l), (m)
	Sound exposure to an air transport facility	(l), (m)
Buyers' and sellers' characteristics (◁)		
Income		(n)
Gender		(a)
Age		(a)
Social and occupational group		(a)
Marital status		(a)
Municipality of origin		(a)

Sources: (a) PERVAL, (b) geographic directory of municipalities, (c) Chambers of Commerce and Industry database, (d) municipal database, (e) phone book, (f) topology database of National Geographical Institute, (g) building database of National Geographical Institute, (h) database for classified plants per municipality, (i) land use plan, (j) prefecture, (k) Regional Office for Environment, Planning and Housing, (l) sound map of Departmental Office for Territories and Sea, (m) sound map of Technical Studies Center of Public Works, (n) statements of income from the General Directorate of Public Finances.

Notes: each distant to a facility is built as the distance to the closest facility.
(∗) Distance or commuting time to central business district is computed as the distance or commuting time to the town hall of Bordeaux, Dunkirk or Rouen.
(⋆) Living space is filled in for 81% of observations near Bordeaux, 80% near Dunkirk and 62% near Rouen. The imputed value for missing values is randomly chosen among the observed distribution of living spaces.
(†) Most hazardous plants among the classified plants for the environment protection (mainly Seveso sites).
(‡) Plants subject to the regime of classified plants for the environment protection.
(⋄) View from the dwelling of red and white Petroplus chimney or of Senalia silo.
(▷) Area of servitude or notification.
(◁) This information is relative to the buyer (or seller) himself, or to the household reference person.

[34]The effective distance between the dwelling and the plant is used by all studies relative to the impact of similar industrial risks on housing prices (Table 13 in Appendix A.2). Other variables are added in some studies, such as dummies of location in administrative areas for risk management (emergency plans such as in Boxall et al. (2005) and Travers et al. (2009)) or variables traducing perception of pollutions created by the plant (Boxall et al. (2005), Sauvage (1997)).

4 Results

We estimate the hedonic price function with three different models: the baseline parametric OLS log-linear model and two extensions of this model, a parametric OLS log-polynomial model and a semiparametric LWR log-linear model (Section 2). Results of these hedonic regressions are presented near Bordeaux in Table 4, near Dunkirk in Table 5 and near Rouen in Table 6.[35] As expected, recent building, good condition, living space, number of rooms, of bathrooms and of parking lots, area of land, all increase the dwelling value. Presence of outbuildings, of a basement and of a swimming pool can also increase the dwelling price. As variations of commuting time are limited,[36] once including municipality dummies, the commuting time to central business district does not significantly modify the dwelling value.[37] In the three models, signs are the same and orders of magnitude are similar.

4.1 Different impacts of distance to highly hazardous plants between the studied cases

Even among a same category of industries (chemical and petrochemical industries), the impact of distance to highly hazardous plants on the dwelling value varies between the three cases here studied. Near Bordeaux, in all models, proximity to the gunpowder factory is valued in the very close vicinity of the gunpowder (Table 4), probably because the neighborhoods of the plant are green with many trees and very quiet places.[38] Thus, we capture here unobserved amenities which are spatially correlated with the distance to the plant. Near Dunkirk, the semiparametric model reveals that the distance to highly hazardous plants does not significantly impact housing prices (Table 5).[39] Indeed, the presence of

[35] Parametric regressions include municipality dummies and year and month dummies. For the sake of readability, these estimated coefficients are not reported. Some of them are significant at the 1% or the 5% level.

[36] All houses are located between a quarter and half an hour from the center, and even between 6 and 14 min near Dunkirk (Table 10 in Appendix A.2).

[37] When excluding municipality dummies, commuting time is significant in all parametric models. In the semiparametric ones, this effect is captured by the distribution of intercepts, as intercept is allowed to vary with respect to kernel variables, in particular geographic coordinates. All these results are similar when using the geographic distance to central business district instead of the commuting time.

[38] These green areas do not belong to parks. This is why this effect is not captured by the observed distance to parks.

[39] On the contrary, the parametric model indicates that the distance to highly hazardous plants increases housing prices near Dunkirk. This difference is due, not to the nature of the model used, but to the size of the sample used for regressions. Near Dunkirk, the main part of the sample is almost uniformly concentrated between 700 m and 3 km from the highly hazardous plants. In the semiparametric regression, the extreme observations are rarely used and weigh less than the others, whereas in the parametric regression, the whole sample is used and each observation has an equal weight. When restricting the sample to the observations between 700 m and 3 km from the highly hazardous plants, the parametric regression shows that the distance to highly hazardous plants does not significantly impact housing prices.

a nuclear plant in Gravelines (located 18 km from Dunkirk) is likely to overshadow the exposure to industrial risks here studied. Near Rouen, in all models, the distance to highly hazardous plants increases dwelling values (Table 6): highly hazardous plants are perceived as disamenities. The magnitude of this impact is important: on average, households are willing to pay around 1.2% of their dwelling price to go 100 more meters away from highly hazardous plants near Rouen (Table 7). This order of magnitude is consistent with the other studies relative to the impact of similar industrial risks on housing prices (Table 13 in Appendix A.2).

Reviewing other studies relative to the impact of similar industrial risks on housing prices shows that distance to hazardous plants can increase, decrease or have no significant impact on housing prices, depending on the studied case and in particular on the type of industries (Table 13 in Appendix A.2). Clark and Nieves (1994) also show that the proximity to a petrochemical refinery weighs more on the housing prices than the proximity to coal/gas/oil-fires plants, to hazardous waste or to a liquefied natural gas site. Our results confirm this dependency. It seems here to be mainly due to the differences in the perception of industrial activities and of their neighborhoods.

4.2 Testing the fixed-parameter assumption

When comparing the parametric model and the baseline log-linear model, the square or the cube of distance to highly hazardous plants are significant in the parametric model near Bordeaux and Rouen (Tables 4 and 6). This suggests that the fixed-parameter assumption does not hold. The fixed-parameter assumption is properly tested by comparing the semiparametric model and the baseline log-linear model, which corresponds to a nested model under the null hypothesis of fixed coefficients.[40] This hypothesis is rejected at the 0.01% level, which confirms the need for flexible forms and pleads for the use of this semiparametric model.

4.3 Comparing the impacts of distance to plants estimated by the parametric and semiparametric models

We compare the estimated impacts of distance to the plants provided by the parametric log-polynomial model and by the semiparametric model.

[40]See McMillen and Redfearn (2010) for a summary of Cleveland and Devlin's F-test and its adaptation to the LWR regression.

Table 4: Near Bordeaux: parametric and semiparametric hedonic regressions

Model	Log-linear, OLS			Log-polynomial, OLS			Log-linear, LWR		
Explained variable	Dwelling price			Dwelling price			Dwelling price		
Explanatory variable	Estimate	Std. error	p-value	Estimate	Std. error	p-value	Mean	Std. error	p-value (∗)
Intercept	11.4	0.080	$<$ 2e-16	11.6	0.12	$<$ 2e-16	11.3	0.32	$<$1e-04
Less than 5 years	0.16	0.028	6.1e-09	0.16	0.028	9.1e-09	0.14	0.040	$<$1e-04
Average condition	-0.015	0.014	0.29	-0.015	0.014	0.28	-0.032	0.031	0.077
Poor condition	-0.21	0.032	4.3e-11	-0.22	0.032	2.2e-11	-0.20	0.051	$<$1e-04
Living space	0.0020	2.3e-04	$<$ 2e-16	0.0019	2.3e-04	$<$ 2e-16	0.0020	4.4e-04	$<$1e-04
4 rooms	0.25	0.027	$<$ 2e-16	0.26	0.027	$<$ 2e-16	0.22	0.056	$<$1e-04
5 rooms	0.34	0.027	$<$ 2e-16	0.35	0.027	$<$ 2e-16	0.31	0.052	$<$1e-04
6 rooms	0.37	0.030	$<$ 2e-16	0.38	0.030	$<$ 2e-16	0.34	0.063	$<$1e-04
7 rooms or more	0.40	0.036	$<$ 2e-16	0.41	0.036	$<$ 2e-16	0.38	0.071	$<$1e-04
No bathroom	-0.14	0.042	0.0013	-0.14	0.042	8.3e-04	-0.20	0.069	0.018
2 bathrooms or more	0.13	0.016	7.6e-15	0.13	0.016	1.7e-14	0.14	0.030	$<$1e-04
1 parking lot	0.099	0.016	1.1e-09	0.097	0.016	1.7e-09	0.078	0.020	0.0014
2 parking lots or more	0.15	0.025	1.0e-09	0.15	0.025	2.3e-09	0.12	0.046	3.0e-04
Presence of outbuildings	0.052	0.021	0.013	0.051	0.021	0.015	-0.034	0.023	1.0
Presence of a basement	0.12	0.030	2.7e-05	0.12	0.030	2.8e-05	0.056	0.048	0.029
Presence of a swimming pool	0.13	0.019	1.4e-11	0.13	0.019	2.6e-11	0.22	0.032	$<$1e-04
Area of land	1.6e-05	6.1e-06	0.0092	2.0e-05	6.5e-06	0.0016	5.0e-05	4.0e-05	$<$1e-04
Commuting time to CBD (†)	1.1e-04	6.6e-05	0.11	7.5e-05	6.7e-05	0.27	1.5e-04	1.7e-04	0.27
Distance to plants (‡)	-2.7e-05	8.9e-06	0.0025	-1.4e-04	5.4e-05	0.012	-2.0e-05	2.0e-05	0.022
(Distance to plants)^2				2.7e-08	1.2e-08	0.026			
(Distance to plants)^3				-1.8e-12	7.8e-13	0.019			

Notes: parametric regressions include municipality dummies and year and month dummies. These estimated coefficients are not reported. Some of them are significant at the 1% or 5% level.

(†) CBD = Central Business District; (‡) plant denotes a highly hazardous plant.

(∗) See McMillen and Redfearn (2010) for a summary of Cleveland and Devlin's F-test and its adaptation to test the significance of explanatory variables in the LWR regression.

Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of South West France, statements of income from the General Directorate of Public Finances. 1,423 observations.

Table 5: Near Dunkirk: parametric and semiparametric hedonic regressions

Model	Log-linear, OLS			Log-linear, LWR		
Explained variable	Dwelling price			Dwelling price		
Explanatory variable	Estimate	Std. error	p-value	Mean	Std. error	p-value (∗)
Intercept	10.9	0.075	< 2e-16	10.9	0.11	<1e-04
Average condition	-0.071	0.018	8.8e-05	-0.09	0.023	0.0098
Poor condition	-0.25	0.021	< 2e-16	-0.23	0.052	<1e-04
Living space	0.0011	3.3e-04	6.1e-4	0.0016	0.0012	<1e-04
4 rooms	0.15	0.032	1.5e-06	0.12	0.030	0.0041
5 rooms	0.24	0.031	1.1e-14	0.20	0.041	<1e-04
6 rooms	0.30	0.035	< 2e-16	0.24	0.063	<1e-04
7 rooms or more	0.32	0.044	7.6e-13	0.24	0.099	<1e-04
No bathroom	-0.089	0.029	0.0022	-0.094	0.044	0.019
2 bathrooms or more	0.14	0.035	8.4e-05	0.13	0.047	0.013
Presence of outbuildings	-0.038	0.022	0.080	-0.032	0.032	0.12
Presence of a basement	-0.013	0.017	0.45	0.022	0.030	0.43
Area of land	2.1e-04	3.1e-05	1.1e-10	5.0e-04	2.1e-04	<1e-04
Commuting time to CBD (†)	4.6e-05	1.3e-04	0.72	7e-05	1.8e-04	1.0
Distance to plants (‡)	9.5e-05	2.2e-05	1.6e-05	8e-05	2e-05	1.0

Notes: parametric regressions include municipality dummies and year and month dummies. These estimated coefficients are not reported. Some of them are significant at the 1% or 5% level.
(†) CBD = Central Business District; (‡) plant denotes a highly hazardous plant.
(∗) See McMillen and Redfearn (2010) for a summary of Cleveland and Devlin's F-test and its adaptation to test the significance of explanatory variables in the LWR regression.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Nord and Picardy, statements of income from the General Directorate of Public Finances. 1,016 observations.

Table 6: Near Rouen: parametric and semiparametric hedonic regressions

Model	Log-linear, OLS			Log-polynomial, OLS			Log-linear, LWR		
Explained variable	Dwelling price			Dwelling price			Dwelling price		
Explanatory variable	Estimate	Std. error	p-value	Estimate	Std. error	p-value	Mean	Std. error	p-value (∗)
Intercept	11.1	0.21	< 2e-16	10.8	0.23	< 2e-16	11.0	0.27	<1e-04
Average condition	-0.061	0.026	0.020	-0.059	0.026	0.025	0.028	0.040	0.93
Poor condition	-0.31	0.042	2.2e-13	-0.31	0.041	2.7e-13	-0.29	0.068	<1e-04
Living space	0.0017	3.6e-04	3.7e-06	0.0018	3.6e-04	2.0e-06	0.0019	5.8e-04	0.0011
4 rooms	0.22	0.040	2.9e-08	0.21	0.039	1.2e-07	0.22	0.055	<1e-04
5 rooms	0.34	0.039	< 2e-16	0.34	0.039	< 2e-16	0.36	0.071	<1e-04
6 rooms	0.40	0.044	< 2e-16	0.39	0.043	< 2e-16	0.34	0.052	<1e-04
7 rooms or more	0.47	0.049	< 2e-16	0.46	0.048	< 2e-16	0.43	0.065	<1e-04
2 bathrooms or more	0.14	0.030	6.0e-06	0.14	0.030	4.9e-06	0.087	0.059	0.0028
1 parking lot	0.077	0.030	0.010	0.064	0.030	0.030	0.10	0.038	0.29
2 parking lots or more	0.12	0.035	5e-04	0.11	0.035	0.0017	0.11	0.063	0.046
Presence of outbuildings	0.040	0.029	0.17	0.042	0.029	0.15	-0.014	0.035	0.59
Presence of a basement	0.098	0.024	3.5e-05	0.092	0.023	1.0e-04	0.078	0.024	0.0077
Area of land	2.4e-05	9.3e-06	0.010	2.5e-05	9.2e-06	0.0074	8.0e-05	5.0e-05	<1e-04
Commuting time to CBD (†)	-1.5e-04	1.3e-04	0.25	-6.5e-06	1.4e-04	0.96	-1.1e-04	1.7e-04	1.0
Distance to plants (‡)	1.3e-04	2.1e-05	3.7e-10	2.6e-04	4.7e-05	4.4e-08	1.2e-04	5.0e-05	<1e-04
(Distance to plants)^2				-3.3e-08	1.1e-08	0.0021			

Notes: parametric regressions include municipality dummies and year and month dummies. These estimated coefficients are not reported. Some of them are significant at the 1% or 5% level.
(†) CBD = Central Business District; (‡) plant denotes a highly hazardous plant.
(∗) See McMillen and Redfearn (2010) for a summary of Cleveland and Devlin's F-test and its adaptation to test the significance of explanatory variables in the LWR regression.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, statements of income from the General Directorate of Public Finances. 571 observations.

Value. Parametric log-polynomial regressions lead to a bias in the estimated value of the impact of distance to highly hazardous plants on dwelling prices. Near Bordeaux and Rouen, this implicit price of distance d to these plants equals the absolute marginal willingness to pay $AMWTP$ to go one more meter away from highly hazardous plants (Section 2). To make comparisons between dwellings or between the three cases easier, we also compute the relative willingness to pay $RMWTP$ to go further away from the plants, which expresses this willingness to pay as a percentage of the price of the considered dwellings to go 100 more meters away from the plants.

$$AMWTP = \frac{\partial P(X)}{\partial d}, \qquad RMWTP = \frac{\partial P(X)/\partial d}{P}.$$

Table 7 properly compares the absolute and relative marginal willingnesses to pay, as estimated by the parametric and semiparametric models.

Table 7: Households' marginal willingness to pay to go one more meter away from highly hazardous plants

	MWTP estimated by log-polynomial, OLS			MWTP estimated by log-linear, LWR		
	Median	Mean	Std. Dev.	Median	Mean	Std. Dev.
Near Bordeaux						
AMWTP (€/m)	-3.65	-5.32	5.24	-3.36	-3.17	3.89
RMWTP (%/100m)	-0.19	-0.25	0.21	-0.19	-0.20	0.21
Near Dunkirk						
AMWTP (€/m)	9.45	10.00	3.91	-	-	-
RMWTP (%/100m)	0.95	0.95	0	-	-	-
Near Rouen						
AMWTP (€/m)	19.33	20.25	11.16	14.39	15.44	9.91
RMWTP (%/100m)	1.88	1.67	0.68	1.22	1.20	0.51

Notes: in the parametric regression, the log of price is explained by the linear expression of dwelling characteristics and by a polynomial of the distance to the plants (Equation 4). In the semiparametric regression, the log of price is explained by the linear expression of dwelling characteristics while allowing the coefficients to vary with respect to Z_i, that is with respect to the geographic coordinates, time and the buyer's income (Equation 6). Thus, we get

Log-polynomial OLS Bordeaux:	$AMWTP = (\beta_1 + 2\beta_2 d + 3\beta_3 d^2)P(X)$,	$RMWTP = (\beta_1 + 2\beta_2 d + 3\beta_3 d^2)$,
Log-polynomial OLS Dunkirk:	$AMWTP = \beta_1 P(X)$,	$RMWTP = \beta_1$,
Log-polynomial OLS Rouen:	$AMWTP = (\beta_1 + 2\beta_2 d)P(X)$,	$RMWTP = (\beta_1 + 2\beta_2 d)$,
Log-linear LWR:	$AMWTP = \beta(Z_i)P(X)$,	$RMWTP = \beta(Z_i)$.

Near Dunkirk, willingnesses to pay as estimated by the LWR are not provided, as the distance to the nearest highly hazardous plant is not significant in this model.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, statements of income from the General Directorate of Public Finances. 1,423 observations near Bordeaux, 1,016 near Dunkirk and 571 near Rouen.

The parametric model leads to a biased estimation of the average marginal willingness to pay over the sample, be it the absolute willingness or the relative one, near Bordeaux and

Rouen. Near Rouen, it leads to a clear overestimation: the mean of the absolute marginal willingness to pay and the one of the relative marginal willingness to pay are 31% and 39% respectively higher as estimated by the parametric model than by the semiparametric one (Table 7). It is worth underlining that the bias may lead either to an overestimation or to an underestimation of the average marginal willingness to pay. Indeed, the semiparametric model gives a higher weight to sets of "close" observations (proximity being defined by the kernel in terms of location, time and income), whereas the parametric model gives an equal weight to each observation.[41] If, as here, these sets of "close" observations correspond to a lower marginal willingness to pay than the average, the parametric model leads to an overestimation of the average marginal willingness to pay.

Variations. Near Rouen, the parametric model also leads to a biased estimation (here again a clear overestimation) of the variations of the marginal willingness to pay with respect to the distance to plants.[42]

We perform here regressions that correspond to the second step of Rosen (1974)'s method. The first step is the main hedonic price regression: it estimates the dwelling price $P(X)$ depending of the dwelling attributes X (Tables 4, 5 and 6 in Section 4). The second step here conducted consists in using the implicit price $(\partial P(X)/\partial x_k)_k$ estimated in the first step, by either the parametric or the semiparametric model, to recover information relative to demand and supply. More precisely, we explain the marginal willingness to pay as estimated by the semiparametric regression with the distance to plants, year dummies, buyer's income and also his age, gender, social and occupational group, marital status and location of origin (Table 8). We explain the marginal willingness to pay as estimated by the log-polynomial parametric regression with the distance to plants (Table 8).[43]

These regressions must be considered as essentially descriptive. Indeed, the marginal price of each dwelling's characteristic may vary with the quantity of this characteristic. Thus, households choose simultaneously the quantity and the marginal price for each characteristic. This creates an identification problem in this regression as we explain the willingness

[41] Indeed, OLS can be considered as a special case of LWR: it is a LWR with a windowsize of 100% (the whole sample) and a weight equal to $1/n$ everywhere, n denoting the sample size.

[42] We describe here the relative willingness to pay to go further away from highly hazardous plants. Results are similar when using the absolute willingness to pay.

[43] Indeed, the log-polynomial parametric model does not allow the marginal willingness to pay to vary with respect to time or buyer's income. When explaining the marginal willingness to pay as estimated by the parametric regression also with respect to time of sale and all buyer's characteristics, we find only a significant impact of time (a significant increase in 2002, 2004 and 2006).

to pay to go away from the plants (the marginal price of distance) with the distance to these plants.[44]

Table 8: Explaining households' relative marginal willingness to pay to go one more meter away from highly hazardous plants near Rouen

Explained variable	RMWTP estimated by log-polynomial, OLS			RMWTP estimated by log-linear, LWR		
Explanatory variable	Estimate	Std. error	p-value	Estimate	Std. error	p-value
Intercept	2.6	5.7e-17	<2e-16	1.46	0.16	< 2e-16
Distance to plants	-6.7e-04	3.2e-20	<2e-16	-2.4e-04	1.8e-05	< 2e-16
2002				0.089	0.054	0.10
2004				0.11	0.057	0.046
2006				0.26	0.060	3.1e-05
2008				0.38	0.058	1.7e-10
Income				-1.3e-07	1.2e-06	0.91
Age				1.0e-04	2.2e-03	0.96
Gender (men)				0.064	0.052	0.22
Farmer				-0.043	0.31	0.89
Self-employed				-0.092	0.11	0.39
Laborer				-0.045	0.091	0.62
Manager or professional				-0.060	0.094	0.52
Intermediate lower occupation				-0.049	0.093	0.60
Intermediate upper occupation				-0.062	0.086	0.47
Single				-0.16	0.048	7.4e-4
From more than 15 km (France)				-0.050	0.068	0.46
From abroad				-0.080	0.43	0.85

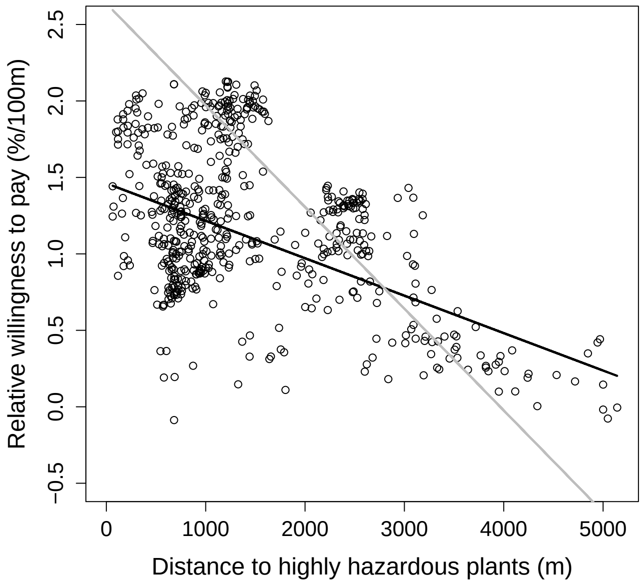
Note: buyer's characteristics are relative to the buyer himself, or to the household reference person.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, statements of income from the General Directorate of Public Finances. 571 observations.

Households' willingness to pay to go further away from highly hazardous plants decreases with respect to the distance to plants over the study area near Rouen (Table 8, Figure 4). This is due to the fact that marginal gains (in terms of exposure reduction) of going further away from the hazard source are likely to decrease. However, two other phenomenons may explain the variations of willingness to pay with respect to the distance to plants. First, other spatially-correlated amenities could bias these estimated variations. Second, there may be a sorting on housing market, uncaptured by buyer's observed characteristics: households with a higher willingness to pay to live further away from the plants may precisely choose a more distant location from these plants. We observe the net result of all three effects; it appears that the first effect dominates the last two ones. The decrease of households' willingness to pay to go further away with respect to the distance to plants is overestimated by the parametric model: corresponding coefficient is threefold higher

[44] Ekeland et al. (2004) offer two methods to implement this second step regression using data from a single market. However, our data do not enable us to apply them, as variability of dwelling attributes with respect to buyers' observed characteristics is required. This simultaneous choice also creates an endogeneity bias in the first step.

(Table 8, Figure 4).

Figure 4: Households' marginal willingness to pay to go one more meter away from highly hazardous plants near Rouen



Caption: The relative marginal willingness to pay to go 100 more meters away from highly hazardous plants, as estimated from the semiparametric model, is a scatter plot. The slope as estimated by the semiparametric model is represented by a dark straight line. The one estimated from the log-polynomial parametric model is represented by a grey straight line.

Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, statements of income from the General Directorate of Public Finances. 571 observations.

In the semiparametric model, households' willingness to pay to go further away from highly hazardous plants increases over time following the 2001 AZF accident,[45] the 2003 law,[46] or 2005 and 2007 information policies (Table 8). Buyer's characteristics that are income, age, gender, social and occupational group do not significantly explain the willingness to pay to go further away from the plants (Table 8).[47] The single have a lower relative willingness

[45]Recall that Grande Paroisse Normandy, which is settled in near Rouen, has a very similar activity to the AZF plant and belongs to the same company, Grande Paroisse (a subsidiary of Total group). Another analysis of the impact of the AZF accident on housing prices near a French facility similar to the AZF plant (Travers et al., 2009) (Port-Jérôme harbor, Seine-Maritime, France) shows the absence of impact of the AZF accident, while using a parametric model.

[46]In the short term, this law implemented the technological disasters insurance system, which improves the coverage of households against technological disasters and should have decreased the marginal willingness to pay. However, even if they were not straightaway effective, other measures of this law with a negative impact on homeowners (such as the implementation of technological risk prevention plans or mandatory information about risks) have been probably more mediatized.

[47]This absence of significant impact holds when considering other specifications (with polynomials or log).

to pay to further away from highly hazardous plants, probably as they have no children. Buyers coming from less than 15 km of the study area have a similar willingness to pay to go further away from highly hazardous plants.

5 Conclusion

Real estate markets can reveal households' willingness to pay to reduce their exposure to hazardous industrial facilities. With highly detailed microdata, we study housing prices in the vicinity of hazardous industries located near three important French cities, Bordeaux, Dunkirk and Rouen. We estimate the impact of distance to hazardous plants on dwelling values by using hedonic price models.

We compare the results from standard parametric hedonic property models and an alternative, more flexible, semiparametric hedonic property model. This semiparametric model is a locally weighted regression that allows this willingness to pay to vary with respect to space, buyers' characteristics and time, while keeping some smoothness in their distribution. If signs and orders of magnitude of effects are similar in the two models for the very wide majority of coefficients, the estimated impacts of the distance to highly hazardous plants on housing prices significantly differ between the two models. The parametric model leads to an important bias in the estimated value of this impact near Bordeaux and Rouen and in its variations with respect to distance to the plants near Rouen.

Using the semiparametric model, we show that this impact strongly differs among industrial areas, even among chemical and petrochemical industries, likely because of different perceptions of industrial risks and dissimilar neighborhoods of these hazardous facilities. We also show that this impact may vary within a study area. Indeed, the impact of distance to hazardous plants on housing prices may significantly decrease with respect to the distance to the plants, as marginal gains in terms of exposure reduction of going further away from the hazard source are likely to decrease; it may also vary over time following accidents or information policies.

There are two substantive lessons that one learns from our analysis. First, our results show that parametric models can lead to an important bias in the estimated value of the marginal willingness to pay. Second, our results show that estimated willingness to pay for prevention strongly differs among industrial areas, even among one category of industries (here chemical and petrochemical industries), and depends on the distance to these facilities and on time. This inadequate estimation method and this limited external validity plead for a careful use of current estimations of population's willingness to pay for industrial risk reduction in the cost-benefit analyses of prevention measures, whereas most cost-benefit analyses have until now used the parameters taken from the estimation of parametric hedonic models on other study area and period than the ones under consideration.

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A Appendices

A.1 Descriptive statistics

Table 9: Intrinsic characteristics of the dwellings

		Bordeaux	Dunkirk	Rouen
N		1423	1016	571
Price (current euro, tax. inc.)	Min	22090	7622	15245
	Q1	146428	76222	92994
	Median	197000	99092	115850
	Q3	256305	128000	154000
	Max	800000	285300	430000
	Mean	206887	104860	126402
	Standard deviation	85661	41021	54707
Less than 5 years old		83	6	15
Condition	Good	497	525	179
	Average	857	297	339
	Poor	69	194	53
Living space (sq m) (∗)	Min	30	46	30
	Q1	95	85	83
	Median	110	95	100
	Q3	134	110	120
	Max	350	300	300
	Mean	119	100	104
	Standard deviation	36	25	34
	Unspecified	260	210	268
Number of rooms	3 or less (†)	109	77	71
	4	361	268	131
	5	506	441	177
	6	288	161	115
	7 or more	159	69	77
Number of bathrooms	0	34	80	0
	1	917	881	450
	2 or more	472	55	121
Number of parking lots	0	304	1016	127
	1	971	0	299
	2 or more	148	0	145
Holds...	... a terrace	83	9	56
	... a swimming pool	207	0	0
	... a basement	72	345	266
	... a cellar	83	47	255
	... outbuildings	161	154	118
	... an attic	70	65	202
Area of land (sq m)	Min	30	0	30
	Q1	606	155	316
	Median	816	207	500
	Q3	1052	305	848
	Max	29597	6599	18724
	Mean	967	266	783
	Standard deviation	1115	261	1355

Notes: the unit is the number of dwellings, unless otherwise specified.
(∗) The imputed living space for missing values is randomly chosen among the observed distribution of living spaces.
(†) Observations with zero room (stand-alone garages, garden sheds or other outbuildings) are excluded.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.

Table 10: Extrinsic characteristics of the dwellings

		Bordeaux	Dunkirk	Rouen
N		1423	1016	571
Commuting time (by car) to city center (min)	Min	16	6	16
	Q1	24	8	19
	Median	28	9	22
	Q3	31	10	25
	Max	38	14	31
	Mean	27	9	22
	Standard deviation	4	2	4
Located close to...	... market square (<500m)	205	295	97
	... a drugstore (<250m)	144	460	109
	... a food shop (<250m)	198	686	214
	... a bus stop (<250m)	676	880	448
	... a park (<500m)	425	714	119
	... a nursery or a primary school (<500m)	428	924	172
	... a high school (<500m)	158	541	161
Distance to the nearest highly hazardous plant (m)	Min	532	41	64
	Q1	3333	837	705
	Median	5141	1730	1140
	Q3	6406	2451	2189
	Max	10379	4084	5142
	Mean	4935	1711	1452
	Standard deviation	1863	949	1027
Distance to the nearest authorized plant (m)	Min	89	41	64
	Q1	1006	596	494
	Median	1657	872	771
	Q3	2663	1163	1189
	Max	5279	1943	2884
	Mean	1848	877	943
	Standard deviation	1061	369	624
View of industrial plants		0	0	495
Located in an administrative area of...	... land use control (Z1)	0	0	34
	... land use control (Z2)	0	0	56
	... emergency plan	0	276	391
	... natural hazard	33	0	0
	... other hazard	0	0	58
	... environmental protection	0	0	61
	... conservation easement	0	39	200
Exposed to...	... land transport noise (⋆)	0	0	15
	... air transport noise (⋆)	79	0	0

Notes: the unit is the number of dwellings, unless otherwise specified.
(⋆) A dwelling is considered as exposed to a land transport facility if sound is above 60 dB / to an air transport facility if sound is above 50 dB.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.

Table 11: Buyers' characteristics

		Bordeaux	Dunkirk	Rouen
N		1423	1016	571
Income (euro)	Min	5024	3471	7550
	Q1	20498	12134	13563
	Median	38815	23266	28958
	Q3	47942	32544	35408
	Max	173016	160996	277797
	Mean	35609	23781	27161
	Standard deviation	16061	12348	17777
	Unspecified	112	64	114
Gender	Female	229	200	99
	Male	1194	816	472
Age (year)	Min	20	20	22
	Q1	34	29	31
	Median	40	34	37
	Q3	48	43	46
	Max	99	82	85
	Mean	42	37	40
	Standard deviation	11	11	11
	Unspecified	0	0	1
Social and occupational group	Farmer	3	1	2
	Self-employed	71	31	31
	Managerial or professional occupation	445	47	77
	Intermediate upper occupation	472	203	188
	Employee	193	112	91
	Worker	103	180	131
	Retired	100	28	41
	No occupation	22	13	7
	Unspecified	14	401	3
Marital status	Single	301	322	172
	In civil union	16	17	7
	Married	884	538	309
	Divorced	158	101	50
	Widowed	34	18	18
Originates from...	... study area	633	758	199
	... less than 15 km away	358	155	324
	... more than 15 km away (France)	391	95	47
	... abroad	11	6	1
	Unspecified	30	2	0

Notes: buyer's characteristics are relative to the buyer himself, or to the household reference person. The unit is the number of buyers, unless otherwise specified.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France, statements of income from the General Directorate of Public Finances.

Table 12: Transactions by municipality and by year

Area	Municipality (INSEE code)	2000	2002	2004	2006	2008	All years
Bordeaux	Le Haillan (33200)	36	31	34	38	24	163
	Martignas-sur-Jalle (33273)	42	40	42	32	30	186
	Mérignac (33281)	13	15	22	13	11	74
	Saint-Aubin-de-Médoc (33376)	34	38	38	28	21	159
	Saint-Médard-en-Jalles (33449)	48	157	155	149	84	593
	Le Taillan-Médoc (33519)	52	50	55	49	42	248
	All municipalities	225	331	346	309	212	1423
Dunkirk	Coudekerque-Branche (59155)	80	77	87	86	85	415
	Dunkirk (59183)	47	35	49	39	41	211
	Fort-Mardyck (59248)	9	12	8	17	16	62
	Saint-Pol-sur-Mer (59540)	50	67	86	56	69	328
	All municipalities	186	191	230	198	211	1016
Rouen	Grand-Couronne (76319)	48	58	57	42	50	255
	Moulineaux (76457)	6	10	4	7	5	32
	Petit-Couronne (76497)	43	45	29	28	38	183
	Sahurs (76550)	10	15	9	9	5	48
	Val-de-la-Haye (76717)	7	7	13	8	6	41
	All municipalities	118	140	113	94	106	571
All areas		529	662	689	601	529	3010

Note: the unit is the number of transactions.
Sources: French solicitors - PERVAL, data collected and standardized by Technical Studies Center of Public Works of Normandy and Centre, Nord and Picardy, and South West France.

A.2 Other studies on industrial risk and housing prices

Table 13: Other studies on industrial risk and housing prices

Study	Hazardous facilities	Region	Time	Sample size	Extrinsic characteristics (*)	Scope of the study area (**)	Variable(s) for risk exposure	Effect of risk exposure
Boxall et al. (2005)	Oil and gas facilities	Central Alberta (Canada)	1994 - 2001	532	Distance to the City, view of mountains	17 km (mean), 7 km (std) (rural area)	Distance to the nearest plant, number of plants within 4 km, number of emergency planning zones the property is located in, sum of H_2S release within 4 km of property	Prices decrease for properties located within 4 km of facilities from 150,000 to 450,000 $CDN 2001, i.e. from -4% to -8%
Carroll et al. (1996)	PEPCON plant (chemistry)	Henderson, Nevada (United States)	1986 - 1990	7,780	No	From 3 to 35 km	Distance to the plant	Prior to explosion, prices increase by 4.17% at 3.2 km from PEPCON, i.e. increase by around $11 per meter. Impact of the explosion on implicit price
Flower and Ragas (1994)	Petrochemical refineries	St. Bernard Parish, Louisiana (United States)	1979 - 1991	1,999	No	From 0 to 3.3 km	Distances to the refineries or dummies for areas based on these distances	In one area prices decrease w.r.t distance. Elsewhere prices increase from $210 to $620 per 100 m, i.e. from 1% to 3.4% per 100 m, i.e. from $2 to $6 per m
Sauvage (1997)	Chemical and petrochemical facilities	Waziers, Puget-sur-Argens, Carling, L'Hôpital and St-Gaudens (France)	1988-1992	170, 64, 59, 91 and 188	No	From 0 to 1.8 km/2 km/4 km	Distance to the plants	In Waziers and in Puget-sur-Argens, no significant impact. Elsewhere, prices increase w.r.t. distance. In L'Hôpital for example, prices increase by 110 F per meter, i.e. around 4% per 100 meter
	Chemical facilities	Bradford (United Kingdom)	1987-1993	561	No	From 0 to 2.5 km	Distance to the plants, view of plants	Prices increase by £5.5 per m, i.e. around 2.6% per 100 meter. View over facilities decreases prices by £960, i.e. by 4.6%
Travers et al. (2009)	Chemical facility	Port-Jérôme, Seine Maritime (France)	2001-2002	228	Distances to roads, highway, Seine, play area, town hall	From 0 to 5 km	Distance to the plants, location in emergency planning zone	Prices increase by €9.2 per m, i.e. by 1.2% per 100 m

(*) Other than variables for risk exposure and dummies for municipalities. (**) The scope of the study area is measured in terms of distance to the nearest plant.

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