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# Environmental risk and differentiated housing values: Evidence from the north of France

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## ABSTRACT

Most of the hedonic literature treats the housing market as a single geographical entity. We use a database with precise information on home characteristics at a property level to show that this is not always correct. We also exploit a refinery closure to address locational sorting and all other unobserved attributes. Refinery closure is associated with an approximately 1.5 µg per cubic metre decrease in SO<sub>2</sub> air pollution, and refinery closure leads to a 6.7% increase in property values with at least 5 rooms or a benefit of approximately 457 million for these households; however, it leads to 28% declines in property values in Dunkirk with one room or a loss of approximately 1 billion for these households.

## 1. Introduction

Assessing the correct impact of environment quality on consumer welfare is crucial for policymakers. To do so, we know from Rosen (1974)'s hedonic model that willingness to pay for a change in natural resources can be inferred on a general differentiated product market. Moreover, Palmquist (1992) demonstrates that hedonic techniques are particularly well adapted to studying localized externalities since the key problems with the hedonic methodology and benefit estimation do not arise. Hence, a large part of the recent economic literature makes use of localized externalities in their analysis because it only affects people in proximity to the externality. Although there may be heterogeneity in preferences in localized externalities, most of the hedonic literature treats the housing market as a single entity. However, the association of a single type of environmental preferences to a geographic area (a tract) may lead to non-reliable measures for regulatory policies. In fact, different type of preferences may be gathered within one single tract and would justify a sub-tract level analysis.

Hence, this article aims to analyse to what extent hedonic prices analysis captures people's willingness to pay for perceived differences in environmental attributes when there may be considerable heterogeneity in preferences in localized changes at a sub-tract level. More specifically, this study on air pollution and house prices analyses the impact of the closure of a toxic site, leading to a change in atmospheric pollution, on the prices of homes near the site. We believe that this study is the first high-resolution empirical analysis to shed light on the heterogeneity in environmental preferences using housing price

characteristics.

While some studies consider heterogeneity in preferences at the tract level (Bayer et al., 2007), very few studies try to analyse heterogeneity in preferences within a tract. Heterogeneity in preferences within a tract has been highlighted in the empirical literature using tract-level median housing values (Gamper-Rabindran and Timmins, 2013; Currie et al., 2015) or buyers' household profiles (Kestens et al., 2006). Kestens et al. (2006) look at the influence of buyers' household profiles on house prices, although this is a source of endogeneity.<sup>1</sup> Gamper-Rabindran and Timmins (2013) find that there is considerable heterogeneity in the capitalization of clean-ups of hazardous waste across the USA based on the entire housing value distribution. Currie et al. (2015) compare estimates from the housing value analysis with a valuation of health impacts at the tract level and find no effects on areas with low birth weights having above-median housing values. Gamper-Rabindran and Timmins (2013) argue only few studies take into account heterogeneity in preferences in localized changes mainly due to data inaccessibility and the lack of fine-resolution data. As recognized by Currie et al. (2015), the main limitation of their dataset is that it contains very limited information related to housing unit characteristics. Using data with very high resolution (at the transaction scale), we go further with this refinement by considering not only the entire housing value distribution but also home characteristics, i.e., the distribution of the number of rooms and the distinction between flats and houses. Further, the estimates are based on tens of thousand of housing transactions. We do so using a difference-in-difference (DiD) strategy.

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<sup>1</sup> Reverse endogeneity is introduced because property prices determine the type of buyer.

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Empirically, some controversial issues may arise when trying to credibly estimate WTP for an environmental change. With heterogeneity in preferences and sorting, it also becomes unclear whose WTP is being estimated (Bayer et al., 2007). An issue frequently associated with the hedonic price model is pollution endogeneity. Hedonic pricing analysis (HPA) considers that pollution is an exogenous variable in the regression of house prices, which is not always correct (Palmquist and Israngkura, 1999). Confounding factors, such as the opening of new businesses, may evolve over time in conjunction with worsening air pollution. In addition, people with high preferences for air quality may sort themselves into locations with good air quality. In this context, the value of the average marginal price of air pollution could be incorrectly estimated.

To mitigate these problems, the main strategy of the recent empirical literature is to use an exogenous source of variation in environmental quality to observe how the quality change was capitalized into housing prices (Chay and Greenstone, 2005), (Currie et al., 2015), (Greenstone and Gallagher, 2008). These capitalization effects are then interpreted as welfare measures (Kuminoff and Pope, 2014). Hence, this study combines the analysis of the heterogeneity in preferences within a tract with a difference-in-difference (DiD) model in an hedonic framework. The literature underscores the need to improve current and to develop novel methods to improve our ability to estimate the marginal WTP for environmental improvements with market data (Bento, 2013; Guignet et al., 2018) and the need to better understanding belief formation around local amenities (Currie et al., 2015; Glennon et al., 2018).

As a tool, the analysis makes use of a French municipality in the Nord-Pas de Calais region, Dunkirk, where a refinery was recently closed. Pollution levels and house prices are compared before and after the closure, both within Dunkirk, namely, the treated group, and in municipalities located within a 50 km radius of Dunkirk, namely, the control group.

All of the people living near a refinery may not be affected by its closure in the same way. Numerous environmental and economical issues exist following the refinery closure that could affect population perception differently. Then, using a combination of two shocks, we are also able to recover heterogeneity in environmental preferences at the sub-tract level.

In fact, in the case of the closure in Dunkirk, there have been both economic and environmental shocks. The environmental shock corresponds to a decrease in the concentration of pollution in the Dunkirk area following the closure. Thus, I assume that the closure of the refinery may have reduced the health risks from air pollution<sup>2</sup> and is likely to have increased the aesthetic value of the site's vicinity. The closure may have enhanced the value of neighbourhood properties. In parallel, the refinery closure produced an economic shock in terms of employment and economic activity around Dunkirk. People living near the refinery with a high or low income may thus be affected differently by the refinery's closure and choose to locate in different areas. As the population became unemployed, the economy of the area stagnated. The slowdown in activity decreased the wealth of people living in the vicinity of the refinery. Economic activity can also have a direct impact on prices and may bias the estimates of the economic benefits of an environmental improvement. Nevertheless, this economic shock appears to have affected the entire Nord-Pas de Calais region in terms of economic outcomes due to the direct and indirect employment consequences of the refinery's closure. While the economic shock has affected the entire sample, the environmental shock affects a specific geographical zone, which enables us to make the distinction between both shocks.

The remainder of the paper proceeds as follows. Section II describes

<sup>2</sup> The severity of respiratory outcomes has decreased following the refinery closure in Dunkirk (Lavaine, 2016).

the situation following the refinery closure, while Section III presents the dataset. Section IV introduces the empirical model and notation. Section V shows that the closure of the refinery led to a reduction in air pollution. Bearing in mind the positive effect of the closure on the aesthetic value of the site's vicinity and on health (Lavaine, 2016), Section VI shows, in parallel, that the effects of the refinery closure on property prices are not always what one might expect. This paper assumes, in a context of localized changes, with potential heterogeneity in preferences, data regarding the capitalization effects at the tract level may fail to provide credible measures of consumer welfare. The rest of the article sheds light on the importance of differences in preferences in a quasi-experimental setting using an empirical framework.

## 2. Pollution, health and the refinery closure

Oil refineries convert crude oil to everyday products, such as gasoline, kerosene, and liquefied petroleum. Crude oil and coal contain a relatively high quantity of sulfur. SO<sub>2</sub> is created when crude oil or coal is heated at a refinery to produce fuel. Therefore, refineries are considered as Seveso sites for most of their activities. In Europe, the "Seveso" Directive applies to approximately 10,000 industrial establishments where dangerous substances are used or stored in large quantities, mainly in the chemicals, petrochemicals, storage, and metal refining sectors. The Seveso Directive compels Member States to ensure that operators have a policy in place to prevent major accidents. This article focuses on sulfur dioxide (SO<sub>2</sub>), one of the major pollutants emitted by oil refineries and the main industrial pollutant. The refining process releases a large number of other chemicals such as benzene and chromium into the atmosphere, which limits our ability to conduct a proper instrumental variable analysis (Lavaine and Neidell, 2017) in the following section.<sup>3</sup> Sulfur dioxide (SO<sub>2</sub>) is one of a group of highly reactive gases known as oxides of sulfur (SO<sub>x</sub>). The largest sources of SO<sub>2</sub> emissions are from fossil fuel combustion at power plants and other industrial facilities (Environmental Protection Agency (EPA), 2011). SO<sub>2</sub> is a colourless gas with a very strong odour. SO<sub>2</sub> is subject to transformation in the atmosphere and can react with other compounds to form small particles. These particles can penetrate deeply into lungs and can cause or aggravate respiratory diseases, such as emphysema and bronchitis (Environmental Protection Agency (EPA), 2011). The severity of respiratory outcomes decreased following the refinery closure in Dunkirk (Lavaine, 2016). However disutility from degraded health is only one part of people's perception of pollution. The literature also emphasizes more broadly the cost of pollution. The health risk due to air pollution may be not only a source of disutility but also physical objects present in an environment; for example, the view of a factory chimney, smoke or possible odour may also have an impact on the perception of populations living near a refinery. SO<sub>2</sub> has a potential impact on plants (crop loss) as well as on buildings and materials (corrosion and erosion) (Krupnick et al., 2002). Individuals' valuations of the lower health risks and any effect on neighbourhood aesthetics may be reflected in the price differential associated with proximity to a refinery, as discussed in the following sections.

While the Flandres refinery, close to Dunkirk in northern France, was a Seveso site, its closure also resulted in crucial economic issues. The refinery produced liquefied gases (propane and butane), fuel for airplanes and automobiles (gasoline and diesel), domestic and industrial fuel, and biofuels. Its refining capacity reached 7.8 million

<sup>3</sup> The greatest challenge in an IV analysis is finding a credible instrument. A valid instrument must have two properties: It has to be correlated with the endogenous treatment variable and uncorrelated with the dependent variable, other than through its correlation with the treatment variable. The exclusion restriction is not met in this article because the levels of other pollutants may have decreased after the refinery closure. Thus, a proper IV analysis is not possible.

tonnes per annum. The refinery employed nearly 370 employees on average, which represented 0.4% of overall employment in Dunkirk. The refinery also worked with 775 establishments, which generated Euros 87 million in annual turnover, including 275 establishments located in Nord-Pas de Calais. Most of the refinery employees lived near their workplace, with two thirds living in Dunkirk. Most of them worked full time on a permanent employment contract and were manual workers. One quarter of the refinery's employees were in intermediate occupations (INSEE, 2010). In September 2009, the production of the refinery was shut down due to poor demand and margins. Given a poor economic outlook, the French oil giant Total announced the definite closure of the refinery in 2010. Due to a large range of subcontractors throughout the region, the closure had an impact on the entire Nord-Pas de Calais region.

### 3. Presentation of the dataset

#### 3.1. Pollution data

Air quality is monitored throughout France (mainland and overseas départements) by 38 approved air quality monitoring associations (AASQAs). The French monitoring station system includes approximately 700 measurement stations equipped with automatic instruments operated by nearly 400 experts. I focus on the concentration of sulfur dioxide (SO<sub>2</sub>) in a radius of 50 km in the Nord-Pas de Calais region, which represents two departments: Nord and Pas-de-Calais.<sup>4</sup> The data used here include daily measures of ambient air pollution concentrations in micrograms per cubic metre ( $\mu\text{g}/\text{m}^3$ ) from all air quality monitors in France for 2008–2011 provided by the Ministry for Ecology, Sustainable Development and Spatial Planning (ADEME) database and more recent data from the National Institute of the Industrial Environment and Risks (INERIS). Fig. 1 provides a map that represents the distribution of monitoring stations in the north of France.

Table 1 presents the summary statistics of all the variables. Monthly pollution concentration data are presented in panel A of the summary statistics, which also provides a measure of expected exposure to SO<sub>2</sub> after eliminating the stations that did not exist during the entire 2008 to 2011 period. Monitoring stations that do not measure SO<sub>2</sub> have also been removed. It should furthermore be noted that only some municipalities have a monitor. The two departments represent 238 municipalities and nine air pollution monitoring stations reporting SO<sub>2</sub> levels.<sup>5</sup>

The summary statistics indicate that the monthly SO<sub>2</sub> concentration decreased after the closure of the refinery. The level was quite low over the period due to the monthly aggregation of daily data. The concentration of sulfur dioxide after the refinery closure in Dunkirk decreased from 8.95 to 5.53  $\mu\text{g}/\text{m}^3$ , whereas the SO<sub>2</sub> concentration in the other municipalities decreased from 4.03 to 3.17  $\mu\text{g}/\text{m}^3$  on average. As a result, the difference in differences between Dunkirk and the control group after the refinery closure was 2.56  $\mu\text{g}/\text{m}^3$ . Fig. 2 shows the monthly evolution of the SO<sub>2</sub> concentration from 2007 to 2011 for Dunkirk, which is considered as the treatment group, and the rest of the municipalities, which is considered as the control group.<sup>6</sup> In this figure, we control for municipality, month and year fixed effect. The SO<sub>2</sub> concentration and the evolution of the SO<sub>2</sub> concentration were higher and more volatile in Dunkirk than in the other municipalities before the refinery closure. Following the refinery closure in 2009, SO<sub>2</sub> pollution decreased in Dunkirk relative to neighbouring municipalities, and the

gap between both groups became smaller. The evolution of the SO<sub>2</sub> concentration from neighbouring municipalities appeared to be rather stable before and after the shock. Graphically, the monthly mean decreased slightly before the refinery closure, which appears to violate the parallel trend assumption between both groups required for the rest of the analysis. This decrease could introduce measurement errors within the following estimations such that the results are suggestive rather than conclusive. The decrease can be linked to the financial and economic crisis that began in the second semester of 2008 and continued into the beginning of 2009. In mid-2009, we observe both the recovery of the world economy and the increase in the demand for oil in 2010. However, this financial and economic crisis hit both groups such that it does not bias the results from the difference-in-difference model. To reinforce the assumption of homogeneity between the treated and control groups, it is necessary to stress that one municipality in the control group includes the port of Calais. Located on the busiest straits in the world for international shipping, the port of Calais alone handles one third of the traffic between continental Europe and the United Kingdom. In this context, Calais and Dunkirk represent two significant commercial ports in France. As part of the control group, Calais strengthens the existence of a similarity between the treated group and the control group. Moreover, the results presented in the remainder of the paper show that our findings still hold when restricting the control group to Calais.

#### 3.2. Weather data and socioeconomic data

Temperature, precipitation, humidity and wind data are used in the analysis to control for their influence on pollution levels, which can in turn affect property values. The weather data come from Meteo France, the French national meteorological service, and include the following: the average and maximum temperature in degrees Celsius; precipitation in millimetres; the maximum wind speed in metres per second; the prevailing wind direction in wind rose; and the maximum and minimum relative humidity in percent.<sup>7</sup> The data are supplied daily by the French weather monitoring system. Measures from one nearby station per department are used as a control in the regression. Weather data are presented in Panel B of the summary statistics.

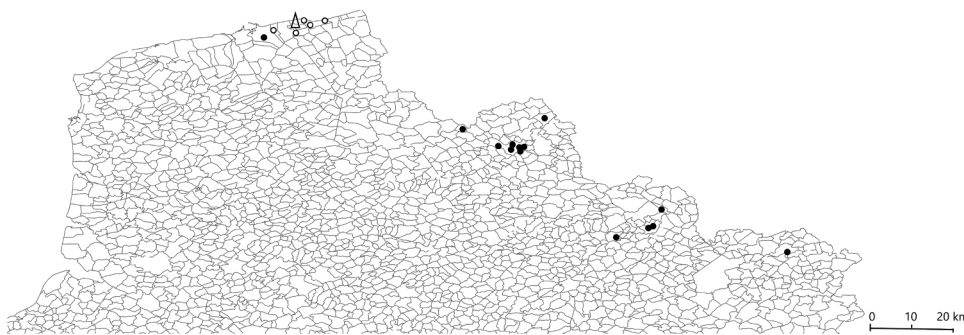
Temperature and the intensity of sunlight play an important role in the chemical reactions that occur in the atmosphere to form photochemical smog from other pollutants. Wind speed and direction measurements are also important for air quality monitoring. If high pollutant concentrations are measured at a monitoring station, the wind data recorded at the station can be used to determine the general direction and area of the emissions. Wind speed can greatly affect the pollutant concentration in a local area. The higher the wind speed is, the lower the pollutant concentration. Wind dilutes pollutants and rapidly disperses them throughout the immediate area. Humidity and precipitation can also affect pollutants in the air to create more dangerous secondary pollutants, such as the substances responsible for acid rain. In contrast, precipitation may have a beneficial effect by washing pollutant particles from the air and helping to minimize particulate matter formed by activities such as construction and some industrial processes (Environmental Protection Agency, 2012). Overall, weather data may act as a proxy to control for seasonality in the regression. However, given that they capture monthly averages, weather effects are likely picked up by the month fixed effects that are also included in the regression model.

<sup>4</sup> A department is a French administrative and geographical level roughly similar to a county in the United Kingdom or the United States.

<sup>5</sup> Differences still exist in observations due to missing data.

<sup>6</sup> 2007 is included in the figure to better observe differences before and after the closure, although it is not included in the following estimations to be in line with the property price model.

<sup>7</sup> The relative humidity of an air-water mixture is defined as the ratio of the partial pressure of water vapor in the mixture to the saturated vapor pressure of water at a prescribed temperature.



**Fig. 1.** Distribution of monitoring stations in the north of France. *Note:* This map represents municipalities' boundaries together with the distribution of monitoring stations in the north of France. Black circles correspond to monitoring stations in the control group, whereas open circles correspond to monitoring stations in the treatment group. The triangle represents the refinery.

### 3.3. Property prices

Property transactions are drawn from the data source PERVAL, which is compiled by the Chambre of Notaires (which in France records property transactions), providing the exact address of all property transactions together with the sales price of every and all property transactions between 2008 and 2011 and all publicly recorded housing characteristics. While most analysts only have access to publicly available tract-level data (Gamper-Rabindran and Timmins, 2013), this article uses a very unique and rich dataset on property transactions. In addition, the main advantage of the housing data is that they contain detailed information pertaining to housing unit characteristics; these details were not included in articles on the same topic (Currie et al., 2015; Gamper-Rabindran and Timmins, 2013). We have information about every property transaction in a radius of 50 km around Dunkirk.<sup>8</sup> The geographic region for the control group is then represented by all towns with centers within 50 km of the refinery in Dunkirk. Nearby municipalities are considered as the control group to control for economic and income shock following the refinery closure. As mentioned before, the economic shock has affected the entire region in term of economic outcomes due to a large range of subcontractors throughout the region. The control variables that are used in the estimation have very few missing values for the dataset to be as exhaustive as possible. Panel C of Table 1 presents the main characteristics of the property transactions together with the sale prices. The summary statistics shows that average property prices increased after the refinery closure, hinting at a potential effect from the closure. The dataset contains 2848 and 13,870 flats and houses, respectively. The number of properties increased from 8089 before the shock to 8629 after the shock. However, the similar increase observed in the control and treated groups does not bias the results from the difference-in-difference model. The number of properties in the control group increased by nearly 6%, from 1086 to 1,215. The number of properties in the treated group increased by nearly 11%, from 7003 to 7,414. The key variables are the property prices, the number of rooms, the type (flat or house), the property floor area, the presence of an attic, a parking space, and a balcony, and a variable that indicates if the property is less than 5 years old. Using geographical coordinates of the properties, Panel C also provides a distance variable that is a measure of the distance between the refinery and the property transaction. We add information about the demographics of the buyer in Panel D because Banzhaf and Walsh (2008) find that local changes in environmental quality are linked to local changes in community demographics. The variable migrant indicates whether a property was bought by an individual who previously lived in Dunkirk. Single corresponds to a single buyer versus a married one.

Panel E highlights the quarterly rate of unemployment, the number of taxable households, the level of taxable income, the rate of new individual businesses, the rate of new activity production and the rate of

firm creation provided by the National Institute of Statistics and Economic Studies (INSEE). These socioeconomic characteristics, available at the municipality level, are used to control for potential changes in economic activity.

### 4. The estimation

The aim here is to examine the causal relationship between the closure of a refinery, local pollution levels, and property prices in the north of France.

The purpose, first, is to estimate the impact of the refinery closure  $post\_closure_{cm}$  on the concentration of pollution  $Y_{cm}$  captured by the parameter  $\beta_1$  in the following model:

$$Y_{cmy} = \beta_0 + \beta_1 post*closure_{cmy} + \sigma X_{cmy} + \theta_m + \omega_y + \gamma_c + \epsilon_{cmy} \quad (1)$$

where the dependent variable  $Y_{cmy}$  represents the log of the SO<sub>2</sub> pollution concentration within each municipality  $c$  in month  $m$  of year  $y$  according to the presented model.<sup>9</sup> The refinery in Dunkirk ceased its activity in September 2009. Thus, the variable  $post*closure_{cmy}$  is the difference-in-differences estimator and represents the interaction between the post and closure variables.<sup>10</sup> While the variable  $post_{cmy}$  represents the time span after the refinery closure in September 2009, the variable  $closure_{cmy}$ , coded as 1 for Dunkirk, controls for time-invariant unobserved covariates. The control group, coded as zero, represents the remaining municipalities in the north of France with at least one monitoring station.  $X_{cmy}$  is a vector of municipality controls that includes weather controls. An unemployment variable is also added to control for changes in economic activity.<sup>11</sup> Time variations in pollution are also controlled for, including month fixed effects  $\theta_m$  and year fixed effects  $\omega_y$ , to limit the influence of pollution outliers. All regressions include a municipality fixed effect  $\gamma_c$  to control for unobserved covariates of pollution which are time-invariant. Finally,  $\epsilon_{cmy}$  represents the error term. This difference-in-differences model assumes the following equation for the model to be valid:

$$\mathbb{E}[\epsilon_{cmy}, post*closure_{cmy}] = 0 \quad (2)$$

where  $\epsilon_{cmy}$  corresponds to the error in the second stage equation of interest. The issue of sorting is thus crucial in this study. Individuals who choose to live near toxic sites may have a low willingness to pay to avoid associated health risks. If consumers value the closure of the refinery, then the closure should cause individuals to sort themselves in such a way that there is an increase in the number of people placing a high value on environmental quality living near the refinery. Hanna and Oliva (2015)'s article supports the idea that the closure may have altered the attractiveness of surrounding neighbourhoods for

<sup>9</sup> When aggregating daily data, the monthly average concentration takes into account monitors without missing data.

<sup>10</sup> The variable  $post_{cmy}$  and  $closure_{cmy}$  are not included in the model because the time and municipality fixed effect remove them automatically.

<sup>11</sup> Unemployment is the only economic variable available in France at both monthly and municipality levels.

<sup>8</sup> The radius of 50 km allows for a sufficient number of municipalities in the control group. These municipalities belong to the same region to reinforce the assumption of homogeneity between the treated and the control groups.

**Table 1**  
Summary statistics [SE].

Variables	Description	The entire period	Before Sept. 2009	After Sept. 2009
Panel A: Pollution concentration; $N = 417$				
Sulfur dioxide (SO <sub>2</sub> )	log of SO <sub>2</sub> concentration ( $\mu\text{g}/\text{m}^3$ )	1.061453	1.215136	0.8515591
Panel B: Weather variables				
Precipitation	Millimetres of precipitation	2.008765 [1.015537]	2.087354 [0.8599679]	1.869306 [1.232342]
Max_Temp	Maximum of temperature °C	14.59093 [6.513577]	14.25712 [6.044898]	15.18327 [7.233453]
Av_Temp	Temperature average °C	10.73392 [5.627273]	10.4839 [5.27849]	11.17759 [6.173196]
Wind_speed	Wind speed (m/sec)	7.827492 [1.123382]	7.956915 [1.17471]	7.597826 [0.9849877]
Wind_direct	Wind direction	206.6803 [44.91593]	211.3447 [40.79121]	198.4032 [50.37515]
Min_Humidity	Relative minimum humidity (%)	60.00654 [11.78418]	60.55584 [10.71448]	59.0318 [13.41971]
Max_Humidity	Relative maximum humidity (%)	93.76189 [2.770849]	92.83191 [2.65916]	95.41219 [2.120282]
Variables	Description	The entire period $N = 10671$	Before Sept. 2009 $N = 5260$	After Sept. 2009 $N = 5411$
Panel C: Property variables				
Price	Euros	148634.8 [93419.96]	146228.1 [67929.61]	150890.8 [112130.4]
Attic	Dummy = 1 if non-convertible <sup>a</sup>	0.1183156 [0.3229911]	.1199159 [0.3248833]	0.1168154 [0.3212188]
Balcony	Dummy = 1 if balcony	0.0401962 [0.196425]	.0374583 [0.1898937]	0.0427628 [0.2023336]
Parking	Parking space in m <sup>2</sup>	0.3385788 [3.57314]	.3825969 [3.583482]	0.2958153 [3.562757]
Surface	Surface in m <sup>2</sup>	97.14408 [44.0163]	96.83583 [41.95927]	97.42974 [45.84205]
Less-5-years	Dummy = 1 if less than 5 years old	0.093492 [0.2911294]	0.1016195 [0.3021659]	0.0858732 [0.280193]
Rooms	Number of rooms	3.668182 [2.328882]	3.781308 [2.243965]	3.562123 [2.401067]
Distance to refinery	Kilometres	28.77932 [18.40296]	28.01549 [15.65355]	29.32535 [20.12316]
Panel D: Buyer characteristics				
Migrant	Dummy = 1 if migrant	0.7061251 [0.4555489]	0.6990975 [0.4586787]	0.7127129 [0.4525229]
Single	Dummy = 1 if single	0.2813136 [0.4496536]	0.2912597 [0.454371]	0.2719898 [0.4450104]
Panel E: Municipality characteristics				
Unemp	Unemployment rate	12.2314 [2.432976]	11.5939 [2.346794]	13.01057 [2.3063]
Taxable income	Euros	24802.49 [10051.05]	26894.51 [10029.69]	22710.46 [9628.117]
Taxable household	Number of taxable households	768.1209 [7011.655]	760.5625 [6996.937]	775.6794 [702]
New production	Production activity creation rate	0.1628178 [0.0788707]	1,878,037 [0.0747833]	0.127507 [0.0705668]
New ind. business	Individual business creation rate	0.1056055 [0.0725373]	1291209 [0.0676829]	0.0723729 [0.0658656]
New firm	Firm creation rate	0.1439529 [0.0785528]	0.1685622 [0.0751812]	0.1091743 [0.0695578]

Note: This table indicates the mean and standard error for the estimation of key variables from 2008 to 2011 in the north of France before the refining process was shut down and after the formal closure of the refinery. There are 13,870 houses and 2848 flats in the dataset.

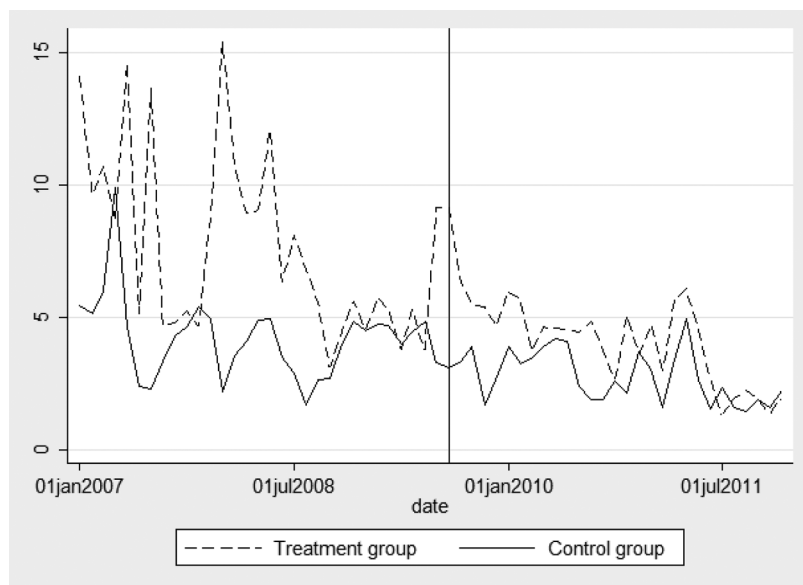
a: Attic = 1 if the attic has not or cannot be converted to a room.

individuals with strong preferences for air quality. If wealthier or healthier people moved closer to the refinery after it was closed, then the estimates might simply be capturing the differences in terms of population characteristics between the old and new residents of the refinery neighbourhood. Although focusing on the years around the closure reduces the probability of selective migration, the change in population after closure in the municipality of interest is also analysed in Table 3.

Similarly, the second objective is to estimate the impact of the refinery closure  $post\_closure_{pcy}$  on property prices  $P_{pcmy}$  or the parameter  $\alpha_1$  in the following model:

$$P_{pcmy} = \alpha_0 + \alpha_1 post^*closure_{pcmy} + \omega W_{pcmy} + \varphi_y + \nu_c + \gamma_m + \sigma_{pcmy} \quad (3)$$

where the dependent variable  $P_{pcmy}$  represents the log price of each property  $p$  within each municipality  $c$  in month  $m$  of year  $y$ . Compared to the previous model, the model is analysed at the year level assuming buying decisions are made over a year. The variable  $post^*closure_{pcmy}$  (PC) represents the interaction variable for Dunkirk after the refinery closure in 2009, as in the previous model.  $W_{pcmy}$  is a vector of the property and municipalities control values and includes property characteristics and the level of unemployment in each area. I also control for variations in property prices over time, including a year fixed effect  $\varphi_y$  and month fixed effect  $\gamma_m$ . All regressions include a



**Fig. 2.** Evolution of the SO<sub>2</sub> concentration from 2007 to 2011. *Note:* This graph represents the evolution of the SO<sub>2</sub> concentration for a municipality with a refinery versus municipalities without a refinery adjusted by month, year and municipality fixed effects. The vertical line corresponds to the period after the refinery closure. We also show the year 2007 to have a better understanding of the trend even if it is not used in the following estimations to be consistent with the transaction model.

municipality fixed effect  $\nu_c$  to control for unobserved covariates of prices that are time-invariant. In fact, many of the variations may be explained by unobserved factors that characterize particular properties, such as geographical features, neighbourhood characteristics and design amenities (Davis, 2004).  $\sigma_{pemy}$  represents the error term.

One of the fundamental assumptions of the hedonic price method is that households have perfect information. If people are not fully informed of the linkages between environmental attributes and benefits to them or their property, then the full value of their homes will not be reflected in property prices. Moreover, the hedonic price schedule does not adjust instantaneously to changes in demand or supply conditions in the housing market. Many factors, such as imperfect information and transaction costs, will then result in the process of adjustment taking some time. In addition, the possibility that the refinery would be definitively closed was evident for some time due to several court rulings at the beginning of 2010. Before October 2010, people might indeed have suspected that the temporary shutdown in September 2009 may become permanent. All buying decisions made throughout the year are therefore included in the model so that changes in house prices from 2010 may be observed three months after the refinery stopped working and ten months before its official closure. In other words, the model of prices takes into account the delay for adjustment to changes in demand as well as the expectations of closure people may have held before the refinery was definitively closed. Although we take into account a delay for adjustment and assume perfect information in localized changes, our quasi-experimental setting is still concerned with a negative income shock, which may have altered the shape of the hedonic prices for some neighbourhoods.

## 5. Results

### 5.1. The concentration of pollution and refinery closure

Looking first at the effect of the refinery closure on air pollution, the results are interesting because they indicate the extent to which refining activity influences the amount of pollution released into the air.

Table 2 details this effect precisely. The table presents the estimate of  $\beta_1$  from Eq. (1), in which the *post\*closure* variable represents the interaction between the post and closure variables. It is a discrete variable coded as one if the municipality is Dunkirk after September 2009 and coded as 0 otherwise. Column 1 presents the impact of the refinery closure on the log of SO<sub>2</sub>. Column 2 adds the unemployment variable as a proxy for the economic activity trend. In the last column,

**Table 2**  
First stage regression.

Variables	(1) ln(SO <sub>2</sub> )	(2) ln(SO <sub>2</sub> )	(3) ln(SO <sub>2</sub> )
Post*closure	-0.301* (0.148)	-0.296* (0.146)	-0.517* (0.248)
Av_temp	0.176 (0.138)	0.111 (0.144)	0.670 (0.374)
Precipitation	0.0154 (0.0381)	0.0135 (0.0428)	0.0365 (0.128)
Max_temp	-0.210 (0.135)	-0.156 (0.143)	-0.593 (0.348)
Speed_wind	-0.118* (0.0561)	-0.0957 (0.0635)	-0.0243 (0.0800)
Direct_wind	-0.000445 (0.000937)	-0.00139 (0.00103)	-0.00383* (0.00211)
Min_humidity	-0.0484** (0.0202)	-0.0413* (0.0215)	-0.109** (0.0382)
Max_humidity	0.0196 (0.0270)	0.00767 (0.0326)	0.157* (0.0838)
Unemp		-0.0100 (0.0815)	0.116 (0.150)
Year FE	x	x	x
Month FE	x	x	x
Municipalities FE	x	x	x
Distance to refinery < 2 km			x
Observations	417	417	60
Adjusted R-squared	0.597	0.544	0.617

*Note:* This table presents the coefficient estimates of the reduced form estimate of the effect of the refinery closure on the log of the concentration of SO<sub>2</sub> at the monthly period at the municipality level. The number of observations differ from the subsequent tables that present results at the transaction level. All regressions are estimated using the fixed effect, with standard errors clustered at the month and department levels. Robust standard errors are presented in parentheses. Statistical significance is denoted by the following: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , and \* $p < 0.1$ .

full advantage is taken of the variation in distance between the refinery and the monitoring station by reducing the dataset to a distance of two kilometres between the refinery and monitors; the objective is to have a more precise measure of the exposure to air pollution. It should be noted that all specifications include the month, year and municipality fixed effects and are clustered by municipality and month. Dunkirk, the municipality in which the refinery was located, shows an average reduction of 30%, which corresponds to nearly 1.5  $\mu\text{g}$  per cubic metre SO<sub>2</sub> in air pollution after the refinery closure. The closure substantially

**Table 3**  
Other effects on the overall sample.

Variables	(1) Taxable income per household	(2) Unemp	(3) Migrant	(4) Single	(5) New production	(6) New ind. business	(7) New firm
Post*closure	4.763 (4.130)	0.103 (0.128)	0.0347 (0.0217)	−0.0271 (0.0253)	−0.00832 (0.0106)	−0.00230 (0.00712)	−0.00748 (0.00936)
Distance	−0.0136** (0.00531)	2.79e-05 (8.17e-05)	0.000102 (0.000317)	−0.000246 (0.000245)	7.78e-05 (6.80e-05)	8.52e-05 (7.10e-05)	7.36e-05 (6.93e-05)
Year FE	x	x	x	x	x	x	x
Month FE		x					
Municipality FE	x	x	x	x	x	x	x
Observations	10,258	10,260	10,260	10,260	10,260	10,260	10,260
R-squared	0.964	0.995	0.119	0.062	0.622	0.667	0.637

Note: This table presents the coefficient estimates of the reduced form estimate of the effect of the refinery closure on demographics at the municipality level. All regressions are estimated using the fixed effect, with standard errors clustered at the year and department levels. Robust standard errors are presented in parentheses. Statistical significance is denoted by the following: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , and \* $p < 0.1$ .

reduced pollution, and it is consistent across models. The estimate is not driven by weather or economic activity characteristics, as unemployment and weather variables have been added in the regression, or by neighbourhood specific trends, as the municipality fixed effect is included in all regressions. Taking distance into account increases the magnitude of the effect while missing many observations. This reduction in pollution may imply significant health impacts. Lavaine and Neidell (2017) show that the reduction in  $SO_2$  due to a temporary refinery closure significantly increases birth weight and gestational age of newborns. People exposed to  $SO_2$  show decreased lung functioning for children and increased respiratory symptoms for adults (World Health Organization (WHO), 2011), asthma crises and ocular rashes (Lecoq et al., 2009). Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract (World Health Organization (WHO), 2011). The effects appear stronger for high levels of exposure, and people with asthma are more sensitive to  $SO_2$ . The number of hospital admissions for cardiopathy and mortality increases on days with high  $SO_2$  concentrations (Finkelstein et al., 2003). Human clinical studies consistently demonstrate respiratory morbidity among exercising asthmatic individuals following peak exposures (5–10 min) to  $SO_2$  concentrations equaling 0.4 ppm, with respiratory effects occurring at concentrations as low as 0.2 ppm for some asthmatic individuals (World Health Organization (WHO), 2005).

## 5.2. Property prices and the refinery closure

We previously underscore a causal effect between the closure of the refinery and a reduction in the concentration of pollution. This section looks at how people perceive both this reduction in the concentration of  $SO_2$  and the change in environmental amenities. In fact, the refinery closure induced a lower health risk (Lavaine, 2016) and an aesthetic improvement in the surrounding neighbourhood. These potential changes in health outcomes and localized amenities after the refinery closure may have also affected property values. The temptation to associate these capitalization effects of the plant closure to perception and MWTP is high. We first look at the effect of the closure on property prices in the market. Then, with heterogeneity in preferences and sorting and to the extent that income varies systematically across neighbourhoods and levels of other housing characteristics, we choose to investigate the local average treatment effect. We investigate a segmented property market model to better understand the mechanism. The dataset is divided into proxies of separated segments (property prices category, house or flat, and size of the property) due to their specificity and differences in price evolution.<sup>12</sup> In the context of a

<sup>12</sup> Some studies use subsamples as a robustness check to estimate the hedonic price function without any economic reason to believe the results of a smaller

localized externality, we are interested in understanding how differences in the content of the treatment affects responses.

In the following property models, the exclusion restriction may be violated if other events happen at the same time as the closure. Nevertheless, it is unlikely that this is the case. The Dunkirk area experienced a significant economic downturn around the period of the study as in other municipalities. Economic activity is evolving constantly in Dunkirk mainly due to its port, which is France's third largest. Dunkirk is well known as a port handling heavy bulk cargoes for its numerous industrial plants. Dunkirk is also France's leading port for ore and coal imports, containerized fruit imports, and copper imports, and it is the second most important French port for trade with Great Britain. The port's territory covers 7000 hectares and includes ten towns: Dunkirk, Saint-Pol-sur-Mer, Fort-Mardyck, Grande-Synthe, Mardyck, Loon-Plage, Gravelines, Craywick, Saint-Georges-sur-l'Aa and Bourbourg. Columns 1 and 2 of Table 3 show that the refinery closure did not impact unemployment, taxable income and new activities set up at the census tract level because the coefficients are not significant. After the closure, jobs were indeed offered to the workers of the refinery in other plants or units of Total, the company which had been operating the refinery. Table 3 also introduces the *buyer\_migrant* and *single* outcome variables. These variables are coded as one if the buyer migrates outside Dunkirk or if the buyer is single and 0 otherwise. The refinery closure did not impact the composition of the population because the corresponding coefficients are not significant.

In addition, Fig. 3 provides empirical evidence to support the assumption of parallel trends. Although the unemployment rate is higher in Dunkirk, it shows a similar evolution of unemployment between the control group and the treated group over the period and provides indications of underlying economic trends. There are limited economic data available at such high temporal and spatial resolution; thus, we plot the unemployment rate, which is available quarterly at the census tract, over time for the treatment and control groups.<sup>13</sup> The unemployment time series increases over the period and serves as a time trend in the analysis. The estimation from the hedonic model suggests the proportion of the total variance attributed to unemployment is only 0.66%. This result is not surprising, given that there were only 370 workers at the refinery and that those 370 workers were offered jobs in other plants or units of the refinery group.

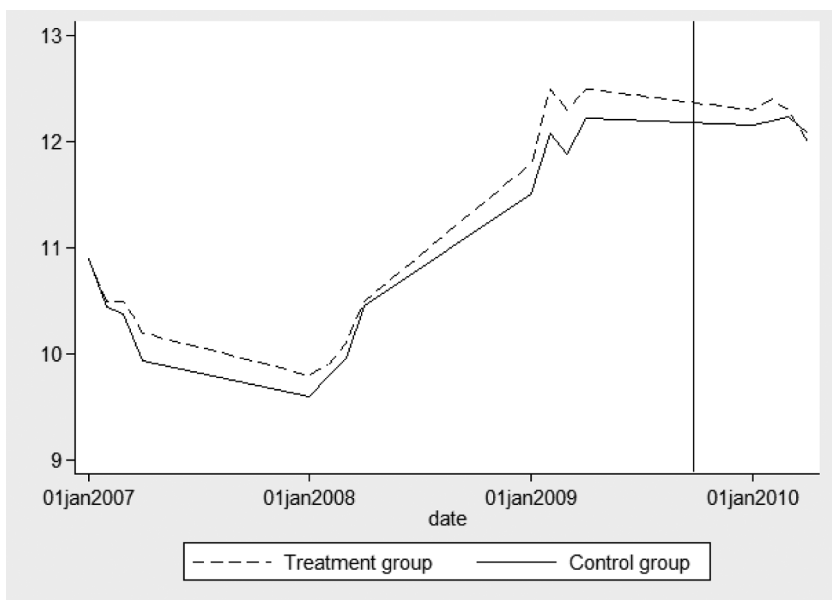
In this empirical application, as in Currie et al. (2015), all residents near or far from the refinery live in the Nord-Pas de Calais region, and I

(footnote continued)

sample should be consistent with the overall sample (Kuminoff and Pope, 2014). The resulting econometric estimator for marginal effects are generally biased and inconsistent when partitioning the dataset (Wooldridge, 2010).

<sup>13</sup> Unemployment is only reported at the quarterly aggregate levels (INSEE) rather than the monthly level for accuracy reasons.



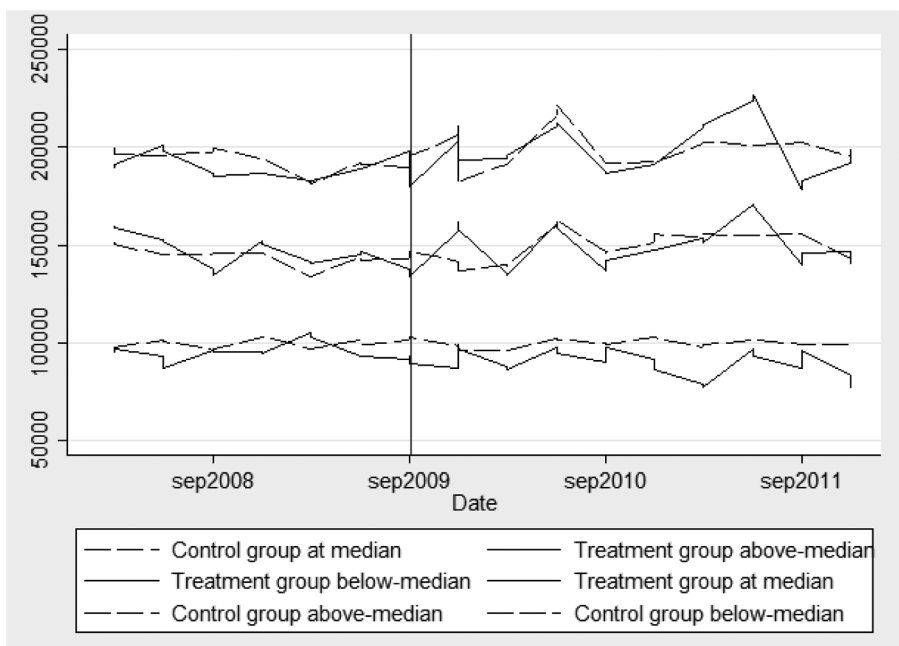


**Fig. 3.** The evolution of unemployment from 2007 to 2011. *Note:* This graph represents the quarterly evolution of unemployment for the area of Dunkirk versus municipalities without a refinery within a radius of 50 km of Dunkirk. The vertical line corresponds to the period after the refinery closure. We also show the year 2007 to have a better understanding of the trend even if it is not used in the following estimations to be consistent with the transaction model.

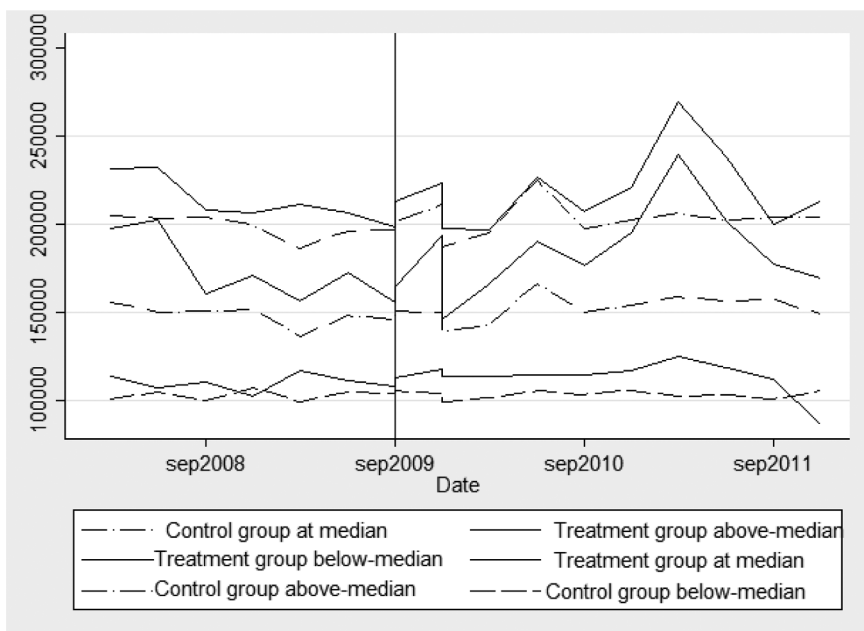
assume that the wage effects are similar for both nearby residents and those living slightly further from the plant. In this context, keeping all other factors fixed, the entire change in property prices following the shock in Dunkirk compared to its counterparts may indicate the extent to which individuals evaluate health risks and any aesthetic effects on the neighbourhood. Considering all ranges of households simultaneously in localized changes may be difficult to interpret. [Feitelson et al. \(1996\)](#) noted that, in theory, hedonic price studies do not require the segmentation of housing markets if all attributes are adequately taken into account. However, in practice, several types of market segmentation are likely to exist in most markets. This is because housing markets are not uniform ([Adair et al., 1994](#)), ([Fletcher et al., 2000](#)). Hence, it is unrealistic to treat the housing market in any geographical location as a single entity. Unfortunately, the definition, composition, and structure of sub-markets have not been given much attention in the hedonic price literature, although this is an important empirical issue. Thus, the heterogeneity of the treatment results is tested here by splitting the sample into house and flat types, different

nominal price levels or property sizes.

[Fig. 4](#) provides quarterly plots of the evolution of all property prices, above-median prices and below-median prices from 2008 to 2011 for Dunkirk and municipalities far from Dunkirk. All the traces are presented in a single figure. The sample is restricted to the Nord-Pas de Calais region. Whereas the below-median price sample shows a decrease in property prices, the above-median price sample shows a slight increase in prices. Alternatively, price plots are presented for houses versus flats in [Fig. 5](#) and [Fig. 6](#), respectively. After the closure of the refinery, house prices increased faster than before in Dunkirk relative to counterpart municipalities where the house price evolution was rather stable. However, it appears that the effect began with the official closure (October 2010) and not during the temporary shutdown (September 2009). The decreased SO<sub>2</sub> concentration in Dunkirk relative to its counterpart municipalities, as observed in [Fig. 5](#), after the refinery closure is correlated to the increased house prices in Dunkirk relative to its counterpart municipalities. In fact, [Fig. 5](#) shows a gap after the refinery closure between the evolution of property prices in Dunkirk



**Fig. 4.** Evolution of property prices around the median of prices from 2008 to 2011 by quarter. *Note:* This graph represents the evolution of property prices above the median of prices for a municipality with a refinery versus municipalities without a refinery adjusted by month, year and municipality fixed effects and aggregated quarterly. The vertical line corresponds to the period after the refinery closure.

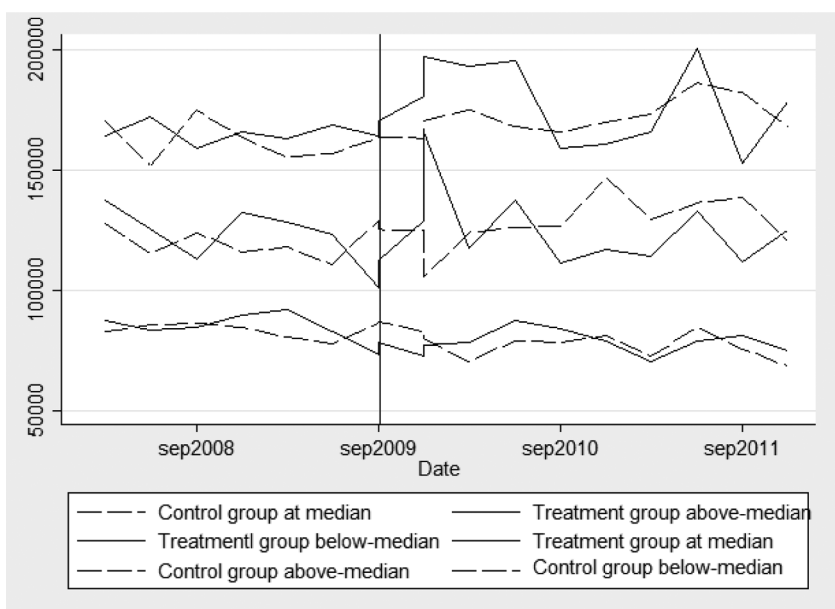


**Fig. 5.** Evolution of house prices around the median of prices from 2008 to 2011 by quarter. *Note:* This graph represents the evolution of property prices above the median of prices for a municipality with a refinery versus municipalities without a refinery adjusted by month, year and municipality fixed effects and aggregated quarterly. The vertical line corresponds to the period after the refinery closure.

relative to the control group; this gap was not observed before the closure in the above-median price sample. We observe fewer differences in the evolution of flat prices, as shown in Fig. 5, between the treatment and control groups. Figs. 4–6 enhance the fluctuations in the evolution of property prices that may be different between the treatment and control groups and may lead to measurement errors, suggesting that the results are suggestive rather than conclusive. However, the fluctuations become smaller when looking at the yearly trend instead of the monthly trend before the refinery closure. Moreover, the transaction decisions in the housing market are made over a year rather than over a month, reinforcing the parallel trend assumption.

Table 4 details this effect more precisely. First, Table 4 presents the effect of the refinery closure on the overall property market. The municipality, month and year fixed effects are included in all of the columns. While the first block of Table 4 looks at the entire dataset, the last two blocks divide the dataset between flats and houses due to potential differences in the evolution of their markets and prices. Column 1 uses a difference-in-difference model without property characteristics.

Column 2 takes full advantage of the control variables. Property characteristics are added to control for any differences in the evolution of property characteristics between the treatment and control groups. The unemployment variable in each municipality controls for any differences in the activity trend between the treatment and control groups. The distance between the refinery and properties controls for differences in exposure to pollution. The estimates are negative and significant for the overall sample, as shown in the first two columns of Table 4. The difference-in-difference estimator is again negative and significant when considering the flat subsample in the third and fourth column. However, estimates are positive and significant for the housing subsample in the last two columns. After the refinery’s closure, while the prices of flats decreased significantly, by 9% on average, prices for houses increased significantly, by 6% on average. Table 5 repeats previous estimations, keeping Dunkirk as the treatment sample but restricting the control group to Calais to reinforce the assumption of homogeneity between the control and treatment groups as explained previously. The results highlight a significant effect of the refinery



**Fig. 6.** Evolution of flat prices around the median of prices from 2008 to 2011 by quarter. *Note:* This graph represents the evolution of property prices above the median of prices for a municipality with a refinery versus municipalities without a refinery adjusted by month, year and municipality fixed effects and aggregated quarterly. The vertical line corresponds to the period after the refinery closure.

**Table 4**  
Reduced form regressions: effect of the closure on the property market.

Variables	(1) Overall market	(2)	(3) Flat	(4)	(5) House	(6)
Post*closure	−0.0655*** (0.00933)	−0.0196* (0.00901)	−0.231*** (0.0271)	−0.0987** (0.0405)	0.0587*** (0.0157)	0.0613*** (0.00621)
Distance		5.10e-05 (0.000299)		0.0976*** (0.0115)		−6.75e-05 (0.000303)
Unemp		−0.0340 (0.0214)		−0.0793 (0.0611)		−0.0247 (0.0184)
Terrace		0.108*** (0.0222)		0.0452* (0.0212)		0.157*** (0.00962)
Attic		−0.0292** (0.00871)		−0.0223 (0.0368)		−0.0158* (0.00716)
Balcony		0.136*** (0.0181)		0.101*** (0.0143)		0.0767 (0.0469)
Parking		−0.000708 (0.000952)		−0.000303 (0.00243)		−0.000482 (0.000597)
Surface		0.00569*** (0.000184)		0.0101*** (0.000424)		0.00524*** (0.000129)
Less-5-years		0.372*** (0.0399)		0.603*** (0.0854)		0.309*** (0.0141)
Rooms		0.0377*** (0.00544)		0.0348* (0.0158)		0.0320*** (0.00444)
Year FE	x	x	x	x	x	x
Month FE	x	x	x	x	x	x
Municipality FE	x	x	x	x	x	x
Observations	10,671	10,260	2172	2068	8499	8192
R-squared	0.140	0.503	0.126	0.632	0.179	0.489

Note: This table presents the coefficient estimates of the reduced form estimate of the effect of the refinery closure on the property market. All regressions are estimated using the fixed effect, with standard errors clustered at the year and department levels. Robust standard errors are presented in parentheses. Statistical significance is denoted by the following: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , and \* $p < 0.1$ .

**Table 5**  
Effect of the closure on the property market: sensitivity compared with the control group.

Variables	(1) Overall market	(2)	(3) Flat	(4)	(5) House	(6)
Post*closure	−0.0397** (0.0156)	−0.0407*** (0.00813)	−0.140** (0.0567)	−0.105*** (0.0270)	0.0505 (0.0342)	0.0147*** (0.00400)
Distance		0.0230 (0.0169)		0.109*** (0.0130)		−0.00742 (0.0172)
Unemp		−0.130* (0.0600)		0.0841 (0.151)		−0.315*** (0.0237)
Terrace		0.107*** (0.0194)		0.0472 (0.0292)		0.138*** (0.0186)
Attic		−0.0358** (0.0133)		0.0106 (0.0320)		−0.0124 (0.00798)
Balcony		0.155*** (0.0345)		0.0872** (0.0271)		0.267*** (0.0724)
Parking		0.00523** (0.00207)		0.000412 (0.00353)		0.00341 (0.00296)
Surface		0.00661*** (0.000328)		0.0110*** (0.000656)		0.00520*** (0.000353)
Less-5-years		0.613*** (0.0948)		0.685*** (0.105)		0.428*** (0.0362)
Rooms		0.0359*** (0.00850)		0.0176 (0.0186)		0.0401*** (0.00739)
Year FE	x	x	x	x	x	x
Month FE	x	x	x	x	x	x
Municipality FE	x	x	x	x	x	x
Observations	3015	2960	1369	1324	1646	1636
R-squared	0.036	0.537	0.033	0.629	0.164	0.506

Note: This table presents the coefficient estimates of the reduced form estimate of the effect of the refinery closure on the property market restricting the control group to Calais. All regressions are estimated using the fixed effect, with standard errors clustered at the year and department levels. Robust standard errors are presented in parentheses. Statistical significance is denoted by the following: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , and \* $p < 0.1$ .

**Table 6**  
Heterogeneity in localized changes.

Variables	(1) Price < Median	(2) Price > Median	(3) Price > 75% percentiles	(4) Price > 90% percentile
Post*closure	−0.0172 (0.0109)	0.0328** (0.00997)	0.0371*** (0.00953)	0.0674** (0.0225)
Distance	3.12e-06 (0.000298)	0.000366 (0.000999)	0.000606 (0.00219)	0.00376* (0.00186)
Unemp	−0.0321* (0.0146)	−0.0196 (0.0114)	−0.00822 (0.0111)	−0.0222 (0.0291)
Terrace	0.115** (0.0349)	0.0406** (0.0126)	0.0416** (0.0136)	0.0404 (0.0259)
Attic	0.0328*** (0.00648)	−0.0254** (0.00754)	−0.0210* (0.00933)	−0.00295 (0.0111)
Balcony	0.130*** (0.0288)	0.0420** (0.0153)	0.0131 (0.0184)	0.0188 (0.0444)
Parking	0.00164** (0.000481)	−0.00423*** (0.000473)	0.000399 (0.00453)	0.00367 (0.00402)
Surface	0.00387*** (0.000279)	0.00317*** (0.000164)	0.00224*** (0.000133)	0.00189*** (0.000181)
Less-5-years	0.291*** (0.0375)	0.120*** (0.00736)	0.0452*** (0.0129)	0.0327 (0.0230)
Rooms	0.0482*** (0.00324)	0.00431 (0.00405)	0.00663* (0.00299)	−0.000319 (0.00365)
Year FE	x	x	x	x
Month FE	x	x	x	x
Municipality FE	x	x	x	x
Observations	5149	5111	2563	978
R-squared	0.322	0.399	0.365	0.430

Note: This table presents the coefficient estimates of the reduced form estimate of the effect of the refinery's closure on the log price of property by level of property prices. Robust standard errors are presented in parentheses. Statistical significance is denoted by the following: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , and \* $p < 0.1$ .

closure on property prices that is again highly heterogeneous with respect to the subsamples.<sup>14</sup> The results from Table 5 are quite comparable (although smaller for houses) to the previous results with the entire dataset, which we take as further evidence of the robustness of our empirical design.

The difference in the results between houses and flats leads us to wonder about the existence of a potential heterogeneity among neighbourhoods in Dunkirk. Hence, we test for the heterogeneity of the treatment results by dividing the dataset into price categories in Table 6 as a proxy for low- and high-income households. Prices are set below and above the median of property prices in the first two columns. We make use of property characteristics, unemployment variable and distance in all regressions. The median house price is set at EUR 138,000 in the dataset. The estimate is negative but not significant for the below-median price subsample. However, the estimate is positive and significant for the above-median price sample. We also create a subsample of expensive dwellings set above the 75% percentile, at EUR 179,200, and above the 90% percentile, at EUR 230,000. The difference-in-difference estimator is again positive and significant when considering subsamples above the 75% and 90% percentiles. The higher the price of a property is, the higher the size of the impact. After the refinery's closure, property prices above the 90% percentile increased significantly, by 7% on average. The results are in line with Gamper-Rabindran and Timmins (2013)'s valuation of the Superfund cleanup, who show that a focus on the median housing value would have understated the larger effects at the lower tails of the housing value distribution. The results highlight large and significant differences in the estimated parameters of those potential sub-markets; hence, the differences might be accepted as evidence of market segmentation (Vargas, 2016).

In addition, property prices above the median increased by nearly 3.2% after the refinery closure, which suggests an average benefit of a

reduction in pollution of approximately 4416 Euros for each property transaction. The benefits hence accrue to all homeowners as a wealth shock, equal to approximately 3.2% of the property values. It should be noted that this gain underestimates the potential benefit for all properties. In fact, this potential benefit exists as a latent gain on every transaction that has not been realized. In other words, the hedonic pricing analysis ignores the effect of air pollution on the property market as a whole as well as its long-term effects. To compare the perception of the environmental health risk and the benefit in terms of chronic mortality from the refinery closure, I need to estimate benefits on the property market as a whole. Thus, I further estimate the effect of the closure with respect to the property sizes to approximate the effect on the property market as a whole. For this, I use information concerning the property market in the north of France from INSEE (INSEE, 2009). The property sizes can also be seen as another measure of heterogeneity. There is again substantial evidence of heterogeneity across these cuts of the data except that there are no effects on prices in properties with 2, 3 and 4 rooms. Table 7 shows not only a positive effect for properties with at least 5 rooms but also a negative and significant effect for properties with only one room, which reinforces the argument of the role of budget constraints given above. INSEE states there were 89,707 properties in Dunkirk in 2009, out of a total of 1,789,875 in Nord Pas-de Calais as a whole. Out of this total, 786,372 homes had 5 or more rooms, while 62,224 had one room. Thus, 45% of properties had at least 5 rooms in Nord Pas-de Calais, which means that approximately 40,360 properties in Dunkirk also had 5 rooms. Property prices for these homes increased by nearly 6.7% after the refinery closure, as shown in Table 7. This finding suggests there has been an average benefit of approximately 11,339 Euros for each transaction. The mean price for this category of homes was 169,249 Euros. The potential benefit for all properties with at least 5 rooms in Dunkirk thus amounts to approximately 457 million Euros. Similarly, there were approximately 2638 properties in Dunkirk with one room.<sup>15</sup> Property

<sup>14</sup> Taking Calais as the unique control area restricts the number of observations drastically; thus, we have decided not to focus on Calais as a unique control area for the rest of the paper.

<sup>15</sup> <https://www.insee.fr/fr/statistiques/2044350?geo=UU2010-59602sommaire=2133042>

**Table 7**  
The effect of the closure with respect to the size of a property.

Variables	(1) 1 room	(2) 2 rooms	(3) 3 rooms	(4) 4 rooms	(5) 5 or more rooms
Post*closure	−0.284*** (0.0488)	0.0117 (0.0140)	−0.0154 (0.0267)	0.0420 (0.0248)	0.0671*** (0.0112)
Distance	0.0588 (0.0351)	0.0934*** (0.00989)	2.32e-05 (0.000541)	3.81e-05 (0.000284)	−0.000936 (0.00185)
Year FE	x	x	x	x	x
Month FE	x	x	x	x	x
Municipality FE	x	x	x	x	x
Property control	x	x	x	x	x
Unemployment	x	x	x	x	x
Observations	254	817	1467	2461	5273
R-squared	0.687	0.649	0.599	0.458	0.455

Note: This table presents the effect of the refinery's closure on property prices with respect to the size of a property. All regressions are estimated using the fixed effect, with standard errors clustered at the year and department levels. Robust standard errors are presented in parentheses. Statistical significance is denoted by the following: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , and \* $p < 0.1$ .

**Table 8**  
Placebo analysis.

	(1)	(2)	(3)	(4)	(5)
Post*closure	ln(SO2) 0.0430 (0.0771)	Overall market 0.0538 (0.0439)	Flat −0.0246 (0.0578)	House 0.0222 (0.0210)	
Observations	417	10,671	2172	8499	
R-squared	0.570	0.503	0.619	0.488	
Post*closure	Price < Median 0.0641 (0.0497)	Price > Median 0.0217* (0.00936)	Price > 75% percentile 0.0236 (0.0133)	Price > 90% percentile 0.0111 (0.0258)	
Observations	5149	5111	2563	978	
R-squared	0.323	0.399	0.364	0.426	
Post*closure	1 room 0.162 (0.250)	2 rooms −0.0570 (0.0408)	3 rooms −0.0751 (0.0500)	4 rooms 0.0734 (0.0417)	5 or more −0.0306 (0.0403)
Observations	479	597	1169	2154	2,342
R-squared	0.722	0.672	0.635	0.466	0.461
Year FE	x	x	x	x	x
Month FE	x	x	x	x	x
Municipality FE	x	x	x	x	x
Property controls	x	x	x	x	x
Unemployment	x	x	x	x	x

Note: This table presents the coefficient estimates of the placebo analysis using Bailleul as a placebo municipality. All regressions are estimated using the fixed effect, with standard errors clustered at the year and department levels. Robust standard errors are presented in parentheses. Statistical significance is denoted by the following: \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , and \* $p < 0.1$ .

prices for these homes decreased by nearly 28% after the refinery closed, as shown in Table 7. The mean price for this category of homes was 70,272.26 Euros. The potential loss for all properties with 1 room in Dunkirk thus amounts to approximately 1 billion Euros.

To reinforce the validity of our results, we present a placebo analysis in Table 8 by choosing a random municipality as treatment. We choose a random municipality with a high number of transactions within the period as a treatment and repeat the previous estimations in Table 8. We use the municipality of Bailleul as the new municipality of treatment instead of Dunkirk, which has been removed from the estimation. Except for the coefficient of prices above the median, which is significant only at the ten-percent level, we observe no significant effects reinforcing the validity of the previous results.

The results vary substantially with respect to the household and property characteristics being considered. The literature highlights that examining the full housing value distribution can have important policy implications for the results of a hedonic analysis (Gamper-

Rabindran and Timmins, 2013). In this article, I find suggestive evidence that the population living in properties at the higher tails of the housing value distribution, in a house, or with a large number of rooms had a different response to the refinery closure than the population living in properties at the lower tails of the housing value distribution, in a flat, or with a few number of rooms. Despite the decrease in air pollution, the results of this article show that low-income owners, in terms of property and buyer characteristics, do not appear to be concerned by air pollution, as there is a negative significant effect on prices at margins after the refinery closure. In other words, there is no marginal WTA to forego the improvement if we consider low-income households.<sup>16</sup> The estimation of capitalization effects for high-income homeowners appears to be related more closely to their MWTA for a

<sup>16</sup> Of course, it does not mean there is not a non-marginal WTA for this improvement. It could be that we have just moved down the demand curve.

perceived increase in environmental quality than low-income homeowners. For example, (Chay and Greenstone, 2005), considering hedonic regressions of house prices on air quality, persuasively argue that recessions or local economic shocks can simultaneously reduce housing prices in unobserved ways while improving air quality (by dampening economic activity), thus biasing difference-in-difference hedonic estimates of air quality downward.<sup>17</sup> In this context, following an improvement in air quality, the net demand for dwellings by high-income households may increase, leading to the increase in property prices that have the characteristics to satisfy high-income households.<sup>18</sup>

These results provide some indications of the relationship between the refinery's closure and house prices. Unless it is assumed that low-income owners are less informed about the impact of pollution, the objectiveness of the damage function versus the perception derived from the hedonic pricing analysis does not explain differences in the results across income categories. The perception of the decrease in health risks may indeed be smaller than the real decrease in health risks because of imperfect information. Furthermore, because their budget constraints are tight, low-income buyers may face stronger spending constraints than others, forcing their hedonic equilibria to change. In the case of the refinery's closure, the shock has had an impact not only on pollution but also on economic activity. Even if they were aware of air pollution reductions, low-income owners/buyers may suffer a larger economic effect in relative terms than high-income owners/buyers. As in Bauer et al. (2017), the negative economic effects of the closure of the plant dominate potential positive changes in local amenities.<sup>19</sup> However, this result only holds in one market segment and does not apply to the entire housing price distribution. It is also possible that wealthier households are better able to take compensatory measures to protect themselves. We show the complexity of estimating MWTP following a change in environmental quality when there may be heterogeneity in preferences. Even in the context of localized changes, we observe heterogeneity.<sup>20</sup> In Dunkirk, high-income homeowners appeared to experience less of a relative income shock after the closure of the refinery.

## 6. Conclusion

This paper represents a first step toward understanding heterogeneity in preferences in the local external effects of refinery production on the well-being of local residents. First, this article tests the short-term impact of a reduction in air pollution on property prices for municipalities that actually experienced such a decrease in pollution following the cessation of an oil refinery's operations in Dunkirk, in the north of France, in September 2009. With a panel dataset, the best way to isolate the causal effect of the reduction in the SO<sub>2</sub> concentration due to the closure of the refinery is to examine outcome differences between Dunkirk and its counterparts over time. I look at the effects of the closure on local measures of SO<sub>2</sub> concentrations and property prices at

<sup>17</sup> In the same vein, high-income households may take less of a relative income shock and their hedonic equilibria may be relatively more stable than low-income households.

<sup>18</sup> This is due to an increase in the household demand who want to live in the area.

<sup>19</sup> Bauer et al. (2017) focus on a nuclear power plant and not on a refinery production plant.

<sup>20</sup> While the post-change marginal willingness to pay measures for an improvement in air quality may be equal and correspond to the incremental price capitalization for high-income homeowners, the price differential associated with capitalization may not correspond to post-change MWTP for lower-income homeowners. The close relationship between capitalization effects and willingness to pay does not always hold in a quasi-experiment if the hedonic equilibria shifts. While it may hold in a neighbourhood with a stable hedonic equilibria, the relationship may be biased for a neighbourhood where the shock alters the hedonic equilibria.

the tract level. The first results indicate that the closure led to a reduction in the concentration of SO<sub>2</sub>, suggesting that strengthening regulations on SO<sub>2</sub> pollution would yield additional benefits in general.

Second, the aim is to assess heterogeneity in preferences in this context of localized pollution changes. Looking at property prices, this study shows that benefits from the refinery closure can be highly localized. Drawing from a very rich property dataset, our suggested sophistication to the hedonic method — the use of home characteristics — enables the possible detection of localized benefits at the sub-tract level using tract-level data. When we apply this method to the evaluation of the benefits of the refinery closure, we detect significant within-tract heterogeneity. Specifically, our analysis of high-resolution geographical data provides direct evidence that these measures of consumer welfare are highly localized in space. Hence, any analysis focusing on tract-level median housing values to capture benefits that are localized at the sub-tract level would result in a failure to infer the true benefits.

This study provides empirical estimates of relevance for policy use in France. Moreover, it confirms the importance of considering heterogeneity in preferences in the property market when using the hedonic regression technique. Further, an important contribution is in the context of very localized changes, whereby heterogeneity in preferences has to be taken into account. While high-income homeowners may respond to pollution, the results highlight that low-income homeowners may suffer more of a relative income shock. Hence, the results cast doubt on hedonic studies looking at a localized change as a single entity.

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