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Effects of Waste-to-Energy Plants on China's Urbanization: Evidence from a Hedonic Price Analysis in Shenzhen

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Abstract: Along with the accelerated process of China's urbanization, the increasing urban population has put much pressure on solid waste disposal. A speeding-up development plan of waste incineration power generation has been launched in China, which aims to resolve the dilemma where many cities are besieged by waste. However, due to the potential impact on surrounding environment, the site selection of these facilities has encountered protests from local residents. The economic reflection of the non-market public sentiment precisely embodies the prices of surrounding real estate market. Taking Shenzhen city as an example, this paper applies a hedonic price model to evaluate its impact on local housing values. The results show that for every additional kilometer the property is away from WTE (waste-to-energy) plants, the value of real estate can increase by 1.30%. If the distance is restricted to within 5 km, the effect rises to 8.6%, which remarkably increases negative externality. In addition, the depreciation impacts on property in two regions of Shenzhen city are significantly different. Policies for reducing the negative effects of the WTE plants are recommended.

Keywords: waste-to-energy; hedonic price model; NIMBY impacts

1. Introduction

1.1. Background

China's urbanization accelerated sharply after the reform and opening-up policy implemented in the 1980s. Benefiting from the promotion of urbanization [1], residents' living standards have been improved, and the real estate industry has been experiencing a rapid development [2]. However, in the process of urbanization, the most prominent issue is the municipal waste disposal management resulting from concentration of population and increased consumption [3]. The amount of MSW (municipal solid waste) collected (generally, the collected amount of MSW refers to the amount of waste that can be transported to transfer stations and disposal facilities) in China's cities reached 181 million tons in 2014, and its growth rate is still high [4]. The accumulated amount of untreated MSW was inferred to be 3000 million tons. Two-thirds of the large and medium-sized cities except counties are besieged by MSW, and a quarter of them do not have suitable places for landfills [5] due to increasingly expensive land. The problem of waste disposal has become one of the most troublesome issues concerning the environment and people's livelihood, which the government should highly concerned about.

Many developed countries have adopted the waste-to-energy (WTE) technique to dispose MSW since the last century (Incineration plants are also known as WTE plants. The heat from the combustion process is used to generate superheated steam in boilers. The steam is in turn used to drive turbo generators to produce electricity.). This emerging technique, which can quickly reduce volume and thus has an obvious economic advantage [6], has been already promoted in some developing countries [7–9]. There were almost 200 waste incineration plants by the end of 2014 in China, and the government announced that this number would be 300 in 2020. In other words, in order to significantly alleviate the problem of MSW besiegement, more WTE facilities should be constructed.

However, due to a deep apprehension of the dioxin emissions that might result from incomplete combustion of MSW [10], the public has misconceptions about WTE plants in China. In particular, the residents living close to WTE plants often complain about foul smells and even hold protests against their operations. In addition, lacking the necessary propaganda and appropriate regulation, the WTE plants in China seem to be the LULU (locally unwanted land used) projects. LULU projects are mainly the facilities and activities that have significant positive benefits for the whole society but result in potential pollution in the local environment or pose potential threats to the health conditions of neighboring residents [11], e.g., nuclear power plants, waste treatment stations, and chemical factories. The residents' resistant sentiments related to the LULU projects are called the Not In My Backyard (NIMBY) syndrome. For example, residents are willing to pay higher electricity prices to avoid nuclear power plants from built in the vicinity [12], and the nearby marble mining operations can be accepted only after the local residents can obtain a certain amount of compensation [13].

In general, the negative emotions of NIMBY may indirectly affect the local property prices by influencing residents' MWTP (marginal willingness to pay). Some literature on waste treatment in America has verified that these facilities can decrease adjacent property values. Gamble [14] made comparisons among landfill sites at different scales and concluded that large-scale landfills not only lowered the housing price but also reduced the amount of new property construction and sales. In order to find out how an incinerator in Massachusetts affected surrounding housing values, Kiel and McClain [15,16] divided the siting stages of WTE plants into rumor stage, construction stage and ongoing operation stage. They pointed out that the buildings in close proximity to incinerators slightly suffered during the rumor stage, while the negative effect generated at the construction stage was lower than that at the operational stage, i.e., by 3−5%. This indicated that the residents could obviously change the WTP according to their cognition of these facilities. Meanwhile, they argued that the appreciation rates of property adjacent to incinerators could be lower, and the positive effect of distance from sites was only revealed during the operational period. Stephen Farber [17] suggested that WTE plants may lead to a higher depreciation impact on local property value than landfill sites because WTE technology could generate higher potential health risks.

The expected lifetime of WTE plants is about 40 years. A WTE facility's siting and construction are bound to create a strong lock-in effect, which means that the rebuild in the short term should be costly and environmentally unfriendly [18]. Therefore, a long-term view has to be taken when a large number of WTE plants should be constructed in the next decade. Moreover, studying the siting of facilities is equally important. China's waste output is mainly concentrated in urban areas. In fact, in most sustainable cities in the world, such as cities in EU, the siting of WTE plants is in urban areas, even in the city center [19]. Building the plants locally can truly reduce the cost of transportation, but it may result in strong protests from residents nearby considering the special national conditions in China. It is worth mentioning that the waste disposal sites in America are mainly in remote areas. Due to the rapid development process of China, today's suburbs can develop into tomorrow's downtown. Accordingly, the government should take a dynamic viewpoint and pay more attention to the relationship between the urbanization process and WTE plant siting.

In order to study the negative impacts on local welfare caused by incinerators for municipal planning, this paper adopts the hedonic price method to evaluate residents' acceptance of WTE plants. Since Lancaster [20] and Rosen [21] put forward the theoretical foundation in the 1960s and 1970s, the hedonic price model has gradually become a popular method to evaluate how public goods can affect local property values. It has also been widely applied to LULU projects such as garbage disposal facilities [22,23], emissions and leaks of hazardous waste disposal sites [24] and nuclear power plants [25,26]. Many scholars have used this model to study local residents' MWTP for living away from these facilities and have measured the negative externalities. As shown in Table 1, residents had low MWTP for property near LULU facilities. Thus, the values of these houses would decrease at different levels because of the construction and operation of the facilities nearby [27–32]. Shenzhen City, which possesses the maximum amount of WTE plants in China, is chosen as our research object. This paper studies the negative impacts on property in Shenzhen city caused by surrounding incinerators. In addition to carrying out the hedonic price analysis, more attention has been paid to the impacts of time and space. Much interest is also shown in the respective depreciation impacts on property in the suburb and urban area, the results of which could provide some dynamic references for real-estate development and site selection of facilities.

Table 1. Studies concerning LULU facilities or activities.

Study	Period and Region	Facilities/ Activities	Effects on Property Values
Boxall et al. [27]	1994–2001 Alberta	Oil and gas facilities	Sale prices fall for houses located within 4 km of facilities from −4% to −8%. Meanwhile, the depreciation effect can easily be expanded with more frequent extraction activities.
Grislain-Letrémy and Katossky [29]	2002–2008 Bordeaux, Dunkirk, and Rouen	Chemical facilities	The impact of hazardous plants on housing values strongly differs among the three industrial areas. Chemical plants in first two areas have slight impacts on local property values. While in Rouen, prices increase by 4.2% per kilometer.
Zabel and Guignet [32]	1996–2007 Maryland	Leaking underground storage tanks	When a leak site is found, local properties prices will plunge by 5%. The negative effect will increase after public inquiry.
Stefan et al. [31]	2002–2013 Switzerland	Nuclear power plants	After the Fukushima nuclear explosions, prices of houses near the nuclear power plant in Switzerland decreased by 2.3%.
Ihlanfeldt and Taylor [30]	1994–1998 Atlanta	Hazardous waste sites	Hazardous waste facilities in the region have been identified to have a negative impact on adjacent property value. Industrial buildings are affected least, about 57 million, while commodity houses suffer the most negative impacts, about 387 million.
Gamper-Rabindran and Timmins [28]	1990–2000 America	The cleanup of hazardous waste	The cleanup of hazardous waste facilities will generally raise the prices of surrounding property by 14.7%. Properties of low prices are subject to greater impacts as they approach these facilities.

1.2. Contributions

There are at least three distinctive reasons for studying the influence of WTE plants on the housing price.

Firstly, this paper makes full use of public information resources to construct a new micro-data set for our sample city (Shenzhen) and uses the hedonic price model to analyze residents' MWTP for LULU facilities. In fact, since the welfare housing system was abolished in 1998, the real estate market has flourished [33]. On this basis, many domestic scholars have carried out property studies with the hedonic pricing method to estimate families' MWTP for property attributes [34–39]. Our study, which analyzes the negative impacts of WTE plants upon the adjacent property value in China, is an important complement to the previous literature. The results of this study have policy implications for government to properly assess residents' MWTP for WTE facilities such as the issues about site selection and mediating public disputes. Shenzhen city is one of the most prosperous real estate markets in China. In this study, a total of 2119 real estate transaction data is selected in different districts in Shenzhen city from June 2013 to March 2015. The hedonic price model is adopted to estimate the effects resulting from the distances between WTE plants and houses on property values. By means of regression analysis, results confirm that this public facility does have a negative impact on local housing prices; the premium effect of the property for each additional kilometer away from the facility is about 1.30%. However, if the distance is restricted to within 5 km, the effect rises to 8.6%, which remarkably increases negative externality.

Secondly, this paper evaluates the respective depreciation impacts on property in rural area and downtown Shenzhen city. Since the construction level of urban environments in Shenzhen city is at the top of the country, this facilitates the promotion of WTE plants in other cities. Results indicate that property on the border suffered from more negative impacts than that outside the border, i.e., a rate of 2% (traditionally, Shenzhen city was composed of two areas, the Shenzhen special economic zone (called inside the border) and the rest (called outside the border), separated by the border of Shenzhen,. Thus, Shenzhen SEZ was separated from the rest of mainland China (from Hong Kong by another border). Initially, the border control was very strict, and required that mainland China citizens from the Shenzhen special economic zone (SEZ) obtain and hold special permissions for SEZ. Over recent years, the border controls have been gradually weakened, and the permission requirement has also been abandoned. On 1 July 2010, the distinction was eliminated, the original SEZ border control was cancelled, and the Shenzhen SEZ was expanded to the whole city. Therefore, the government tried to avoid densely populated areas with the original siting of these facilities. Selecting a location in the suburbs is of the best interest for the whole society. But it is worth mentioning that the large population in Shenzhen settled down in the former countryside over decades of development, which means that this region located close to the WTE plants may flourish over time. The planning lifetime of incinerators may exceed 40 years. Based on China's rapid urbanization, the government should consider urban-rural spatial evolution and take a long-term and dynamic view with respect to siting.

Lastly, improving these scholars' models [40,41] is the third contribution. Considering the characteristics of real estate development in the urbanization process of China, cross-terms regarding sale year and property area with LULU distance (LULU distance means the distance between the property and LULU projects) were added into regressions. The purpose of this measure is to study whether other variables could have marginal contributions to the negative effects caused by WTE plants. Residents, to a great extent, would pay more to avoid potential health risks when they buy larger houses. In addition, our study suggests that the negative impacts concerning value depreciation significantly exist in each trading year.

This paper is organized as follows. The hedonic price model is presented in Section 2. In Section 3, the study area and sales data are described. Section 4 includes the regression results and analysis. In Section 5, robust test, error analysis and cross-term regressions are carried out. Section 6 concludes.

2. Model

The hedonic pricing method assumes that the housing price has many kinds of characteristics, and the price is the sum of resident's willingness to pay for these characteristics [20,42]. Therefore, different combinations of characteristics would create heterogeneous property. A household is considered to have ordinal utility function in this paper:

$$u = u(j, d, \theta) \tag{1}$$

This means households with income M choose property characteristics and other composite goods j to maximize utility. The price of property is determined by the distance from the property to the adjacent WTE plants and other variables. Thus, the expression is $P(d, \theta)$. The other variables (θ) consist of three types [43]. X_i, Y_i, Z_i represent three types of property attributes. X_i denotes the structure attributes including whether the house is new, floor area, numbers of bedrooms and other internal attributes; Y_i represents the direction attributes that determine the number and distance of supporting facilities around the property; Z_i represents the environmental attributes such as parks, lakes, and other green facilities. The prices of other composite goods are normalized to one. Therefore, the problem of utility maximization can be represented by the following formula:

$$\max_{j,d,\theta} u(j, d, \theta) \tag{2}$$

$$\text{s.t } M \geq j + P(d, \theta)$$

$$\text{The first order conditions are}: \frac{u_d}{u_j} = \frac{\partial P(d,\theta)}{\partial d}, \ \frac{u_d}{u_\theta} = \frac{P(d,\theta)_d}{P(d,\theta)_\theta} \quad (3)$$

The equations above indicate that the MRS (marginal rate of substitution) between the LULU distance and other composite goods is equal to the derivative of the property price with respect to distance. Thus, in order to maximize utility, residents need to make their MWTP for each additional kilometer away from WTE plants equal to the MRS. Meanwhile, household evaluation of LULU distance and other attributes of property must be the same.

Regarding the specific forms of the hedonic price function, models have been used in the literature, including linear (parametric, non-parametric and semi-parameter), Box-Cox, semi-logarithmic, and double logarithmic. After testing these models, Cropper et al. [44] argued that if the attributes were easily observed, linear and quadratic Box-Cox models could produce the smallest mean value with the highest standard error. If not, linear and linear Box-Cox models would be better choices. Goodman and Thibodeau [45] held the opinion that Box-Cox models could be used to convert specific data to replace the paradigm of transcendental functions when theory did not develop into a specific form. However, in the case of the missing variables, complex data transformations could lead to the increasing risk of random error [46]. Kuminoff et al. [47] summarized hedonic pricing methods used in literature and found these methods can accurately recover the MWTP for external attributes. They argued that most literature they reviewed imposed time-constant restrictions on implicit prices because of the long time span. This restriction could result in biased estimates for MWTP. Therefore, attention must be paid to the situation when variables change over time and the existence of fixed effects in Box-Cox conversion. Moreover, panel data could estimate the MWTP more accurately compared to cross-sectional data. Malpezzi [48] suggested in his research that a semi-log linear function had the following advantages: first, it considers the differences in units of independent variables; second, it is easy to interpret coefficients; third, it mitigates heteroskedasticity; fourth, it has simple calculations and fits well with the sample; fifth, it adds specification flexibility into the right-hand side. According to the opinion of Malpezzi, this paper adopts the most widespread semi-log model:

$$LnP = \beta_0 + \beta_1 D + \beta_2 X_i + \beta_3 Y_i + \beta_4 Z_i + \varepsilon \quad (4)$$

3. Data Description

The hedonic price analysis in this paper takes Shenzhen city as the target area and selects a total of 80 properties including 2119 real estate transaction data in six districts (Futian, Nanshan, Baoan, Luohu, Longgang, and Yantian) from June 2013 to March 2015 and analyzes the negative impacts of WTE plants upon the surrounding property. The following section describes the six districts and these facilities, and then provides details about the transaction data.

3.1. Study Area

There are six administrative districts and four functional districts in Shenzhen city (see Figure 1). Shenzhen Municipal Government is located in Futian district. This region is the downtown area of Shenzhen city which focuses on development and construction. In addition, there are no WTE plants located in Futian district. Nanshan district, located at the southwest of Shenzhen City, is the tourist base and full of famous attractions. The WTE plant in its territory is located at the southwest waterfront. Luohu district, the earliest economic development zone in Shenzhen city, is another business center. Its unique facility is surrounded on three sides by mountains. Longgang district, located in the hinterland of Shenzhen city, is sparsely populated and has three WTE plants. The construction of the first incineration power plant in Shenzhen city was in 2003, and the latest operation of a new plant was in 2013. Owning to information asymmetry, the site selections of these facilities have suffered from varying conflicts. As a matter of fact, since the siting should take the wind direction into account and set reducing secondary pollution as the primary target, most facilities are constructed either in a city's periphery or at the foot of hills, except the plant in the Luohu district. Locations of facilities are concerned with urban population density in each region. The on-site treatment of waste may be unfavorable for environmental protection, so the site selections should deal with the trade-off between transportation cost and cleanup expenditure. In densely populated areas, frequent economic activities are bound to produce more MSW. As shown in Table 2, Futian and Luohu districts are densely populated, while Nanshan and Yantian districts have low population density due to the limitation of the terrain. Owning to vast territory with sparse population, residential property in Longgang and Baoan districts is mainly located in the central zone. As a result, facilities in these regions could be built at the edge of the areas. This paper does not analyze property prices in the four functional districts due to the following considerations. Firstly, the four functional districts established for economic development and scientific research have little residential population and related facilities; Secondly, the seven facilities in Shenzhen city are either far away from these districts or separated by continuous hills, which pose limiting impacts upon these districts; Lastly, the real-estate market in these regions is not as prosperous as that in the six administrative districts. Therefore, we limit the transaction data to the six districts.

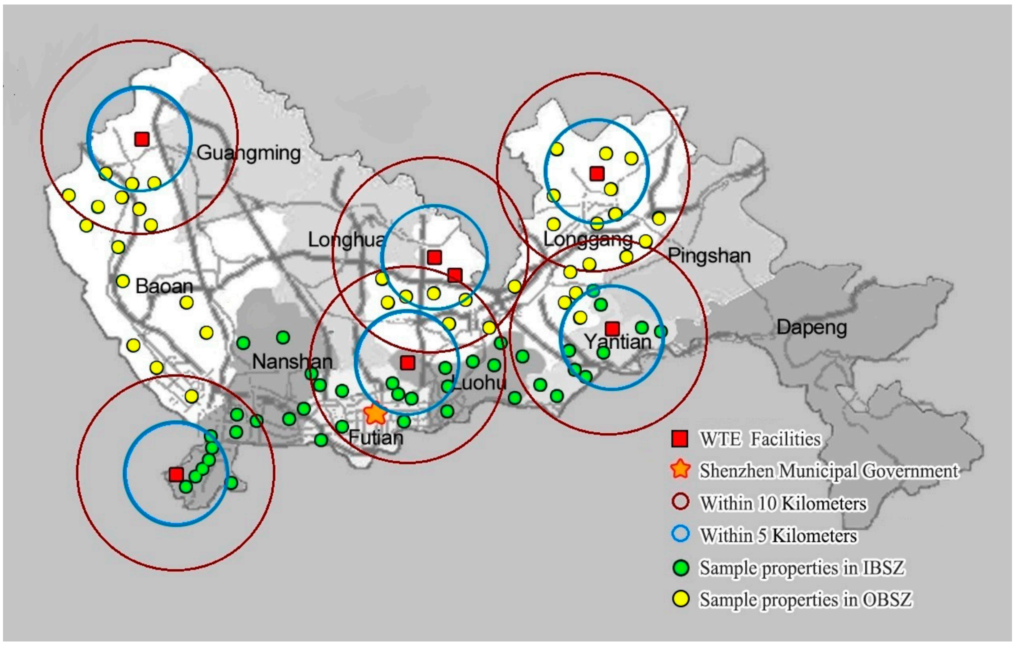

Figure 1. The locations of the sample properties and WTE facilities in six districts in Shenzhen city (a circle means the distance away from the local WTE plants. Considering that two plants are located closely, only one circle is marked.).

Table 2. Regional Information of Shenzhen city.

District	Area (Square Kilometer)	The Resident Population (Ten Thousand)	Population Density (Ten Thousand/sq km)
Baoan	392.14	273.65	0.6978
Longgang	385.94	201.12	0.5211
Futian	78.8	135.71	1.7222
Nanshan	182	108.79	0.5977
Yantian	72.63	20.88	0.2875
Luohu	78.36	93.64	1.1950
whole city	1189.87	833.79	0.7007

Note: The table used data from the Statistic Yearbook [49] of Shenzhen city in 2014.

3.2. Sales Data

The major data source for our analysis is SouFun Holdings Ltd. (SFUN) (Beijing, China). They provided us with detailed transaction data of 80 real estate projects from June 2013 to March 2015, which are reported in Appendix A.1. The sample size is 2119, and the statistical description is represented in Table 3. We obtain the required variables from SFUN and Google Maps including housing prices, sale state, trading year, property location, property area, greening rate, plot ratio, the number of bedrooms, supermarkets, bus stops, hospitals, schools, and parks, and the distances between the property and the nearby central business district (CBD), district government, WTE plants, and open water bodies. Although much previous literature has focused on single-family homes [32], more attention in this paper is paid to high-rise buildings and multiple dwellings due to the high population density. Furthermore, in order to better reflect family purchasing preferences, rental data are excluded.

Table 3 consists of the variables used in the model. This paper has introduced many control variables to correctly estimate the MWTP of residents. Factors such as the age of the house, number of bedrooms, living area, plot ratio, and greening rate are the primary considerations for families to purchase property. In order to facilitate future activities and travel, the related facilities around the property, such as schools, hospitals, supermarkets, bus stops are other factors for making decisions. Generally speaking, the discrepancy in residents' income will significantly affect their choices of residential environment. For instance, wealthy homebuyers may choose to live in urban districts because of their high evaluation of complete facilities. A hedonic study which took another booming real estate market (Beijing) as the target city showed that for each additional kilometer distance away from the CBD, property prices would decrease about 4.8% per square meter [50]. Moreover, with increasing income, families begin to pay more attention to environmental amenities. By means of a survey in Guangzhou, Jim and Chen [40] concluded that nearly eighty percentage of residents acknowledged the significance of local environmental quality. Thus, it is no surprise that property near parks and lakes is sold at higher prices. Similarly, for WTE plants in this study, this paper hypothesizes that these facilities may have negative impacts on property values.

Table 3. The variables and descriptive statistics (sample size is 2119).

Variable	Description	Mean	Max	Min
Ln P	Property transaction price (logarithm)	10.12	11.81	7.27
Structural attributes				
Sales status	Dummy variable (new house = 1)	0.40	1	0
Floor area	Property area	100.16	389.93	24
Plot ratio	Ratio between construction area and coverage area	3.61	10.35	0.96
Bedroom	Number of bedrooms	2.76	6	0
Location attributes				
Supermarket	Number of supermarkets within 3 km	14.51	19	3
Bus station	Number of bus stations within 2 km	9.01	15	0
CBD	Distance from the CBD	16.98	36	1.9
Government	Distance from the local government	7.22	25.4	0.5
School	Number of schools within 2 km	8.92	6	15
Hospital	Number of general hospitals within 3 km	3.80	1	9
Environmental attributes				
Greening rate	Green coverage rate	0.39	0.67	0.15
Park	Number of parks within 3 km	6.07	13	0
Water body	Dummy variable (have open water body within 3 km =1)	0.53	1	0
LULU distance	Distance from WTE plants	7.11	25.1	0.7

4. Regression Results

Table 4 represents regression analysis of Equation (4). All other structural, location, environmental variables, and the distance from WTE plants and property are significant at the 1% level except the variable of bus stops (significant at the 5% level). For ease of understanding, the result analysis takes a typical property with several attributes as an example. On the premise of controlling for other variables, the property price will increase 5.43% if it is just sold. Meanwhile, each additional square meter of the property will increase the price by about 0.11%, and for each additional bedroom, the price may increase by 2.83%. Intuitively, families will purchase property with larger areas to increase residential comfort, if affordable. Of course, some small houses with exquisite decoration also have higher average prices, but in general, larger property is more favorable.

Regarding the control variables of supporting facilities around the property, the increased number of bus stations and schools will significantly raise its price while the impacts can be the opposite when the property is close to supermarkets and hospitals. Locations away from the district center and CBD will decrease the price by 1.20% and 1.88%, respectively. Thus, if the property is located 10 km away from these two places, the price will fall by about 12% and 18.8%, respectively. A comparison of the results of Shenzhen city and those of Beijing city [50] indicates the coefficient of CBD is smaller. Owning to the co-prosperity of different regions in Shenzhen city, other administrative districts (Luohu, Nanshan, and Baoan districts), similar to Futian district, also have perfect financial and commercial sites in their central regions.

Among the environmental variables, the greening rate has a great influence on property value. Considering the urban planning in Shenzhen city, the government would strengthen urban greening construction in conjunction with the original ecosystem to create an international garden city. Hence, residents have strong MWTP for good living environments. This is also reflected in the variables regarding whether open water bodies and parks exist within three kilometers; the result shows that the property value appreciates by 12.8% with lake and sea views. Shenzhen city is full of lakes and coasts, which makes it easy to have real estate with lake and sea views. With increasing income level, residents prefer more greening facilities and beautiful landscapes.

Through the estimation of the variable of the distance between WTE facilities and property, every additional kilometer will significantly push up the housing price by 1.30%, which achieves the desired result. Households will pay higher prices to live away from WTE plants in order to reduce the potential risks posed by these facilities. However, compared to settling down away from the plants, residents show more interest in environmental attributes such as lake views, sea views and parks. Moreover, residents' concern about incinerators is not greater than their worry about living away from schools. Of course, WTE plants are constructed in sparsely populated areas. In Nanshan district, although the minimum distance from the facility to the nearest property is less than 1.5 km, the prices of these properties will not drop dramatically. However, locations away from the facilities may not be a household's prime consideration with respect to purchasing property. Based on information obtained from the Ministry of Environmental Protection of China, no cases have been found where WTE plants in Shenzhen city caused actual harm to local residents (even if the emission reaches the safety regulated limits, it will still contribute to potential health risks). In general, families perceive risk through individual rationalization or the media. For example, the WTE plant in Huizhou city (adjacent to Shenzhen city) makes residents who live downwind bear the risks of having cancer [51] because of imperfect management and regulation. The public protested against WTE plants after the exposure of this event. However, some plants in Shenzhen city have been awarded (Engineering with National Quality) in recent years. In addition, all emissions of pollutants reach the standards (Chinese emission limits are presented in Appendix A.3). According to the study of the LULU phenomenon [52], different interpretation of risks can significantly change residents' perceptions of risks. Meanwhile, occasional disasters will strengthen and promote public aversion thereby further increasing residents' MWTP to stay away from WTE facilities. In order to eliminate residents' misunderstanding and to better promote this technology, the Shenzhen municipal government has organized visits to WTE plants several times. As a result, these facilities in Shenzhen city led to a decline in the prices of surrounding houses, but this was mainly caused by families' inadequate understanding of this technology, rather than the facilities themselves.

Table 4. Estimation results.

Variables	Coef.	Std. Err.	*t*-Value	$p > \lvert t \rvert$
Constant	9.4596	0.0543	174.20	0.000
LULU distance	0.0130	0.0013	10.01	0.000
Structural attributes				
Sales status	0.0543	0.0118	4.60	0.000
Floor area	0.0011	0.0002	7.06	0.000
Plot ratio	0.0161	0.0041	3.93	0.000
Bedroom	0.0283	0.0073	3.87	0.000
Location attributes				
Supermarket	−0.0202	0.0016	−13.01	0.000
Bus station	0.0073	0.0030	2.42	0.016
CBD	−0.0188	0.0007	−28.66	0.000
Government	−0.0120	0.0010	−11.62	0.000
School	0.0483	0.0048	10.13	0.000
Hospital	−0.0253	0.0032	−7.92	0.000
Environmental attributes				
Greening rate	0.4958	0.0609	8.14	0.000
Park	0. 0557	0.0020	27.62	0.000
Water body	0.1278	0.0133	9.63	0.000

R-squared = 0.7628 Adjusted R-squared = 0.7612, N = 2119. Note: Constant is the intercept in the regression, t-Value means the t-statistic, and $p > \lvert t \rvert$ is the level of significance.

5. Robust Test, Error Analysis and Cross Terms Regressions

5.1. Robust Test

The basic model has supported the conclusion that WTE plants may have a depreciation effect on surrounding property values. However, the conclusion may be subjected to the place where the property is located. Concretely speaking, the different regions in Shenzhen city represent significant social distinction which may lead to different regression results. Consideration of the different trading years can verify whether the depreciation effect always exists. Studying different distance intervals is also necessary because the negative externality posed by WTE plants on property values may not be constant. Therefore, it is necessary for us to investigate the robustness of the basic model.

5.1.1. Depreciation Effects in Different Regions

According to the analysis above, 80 properties are divided into two groups in accordance with their geographical locations. One region, on the border of Shenzhen city, is called IBSZ (no specific phrases can express the meaning of the land in the border of Shenzhen city, so we use the abbreviation IBSZ to represent this region. OBSZ is handled in the same way). Similarly, this paper uses OBSZ to refer to the outside region. Adding the dummy variable named IBSZ to the whole sample is used to examine the differences in property prices between the two regions. As a matter of fact, during the reform and opening up period, the Shenzhen Special Economic Zone specifically referred to the land within the border of the city. Economy and culture developed rapidly in IBSZ after the establishment. The two regions implemented entirely different economic policies which made economic and cultural development in the OBSZ significantly lag behind that in the IBSZ. Although the scheme of integrated development was put forward by the Shenzhen Municipal Government in 2010, the discrepancy was still obvious. As shown in Table 5, a comparison of economic development between IBSZ and OBSZ was made. It is clear that IBSZ has better economic foundation than OBSZ, with a slower rate of economic growth. The most prominent gap is the disposable income. IBSZ has complete public facilities and social welfare, which OBSZ cannot match. Although the government has increased investment in construction in OBSZ over the years, people who immigrate to Shenzhen still take IBSZ as the first choice. In addition, there are three plants in IBSZ and four plants in OBSZ.

Therefore, in order to compare the different impacts on property in the two land locations, based on the significant discrepancy in economic development, this paper shows considerable interest in the different depreciation effects in the two regions. Due to the demonstration role of Shenzhen city, there will be reference to the issue concerning whether the siting occurs in a rural or urban area.

The second and third columns of Table 5 report the regression results of the different regions. Property inside or outside the border of Shenzhen city significantly suffered from the decline in values by the surrounding WTE plants in the whole sample period (2013–2015). In IBSZ, the estimated parameter is 3.10%, while the estimation in OBSZ is only 1.07% (less than the estimated parameter of the whole city, 1.30%) and both of them are significant at the 1% level. The average housing prices in IBSZ are significantly higher than those in OBSZ, by 14.4%. Furthermore, the result indicates that the negative impact on property prices in IBSZ is nearly 3 times higher than that in OBSZ. Although there are only two districts outside the border of Shenzhen city, the area is about twice as large as that in IBSZ. In addition to the central area of Baoan and Longgang districts, the edge regions have the lowest population density. Moreover, WTE plants in OBSZ are mainly built at the foot of mountains, which makes them impossible to have huge impacts on surrounding property. The dense population in IBSZ increases the demand for real estate. In addition, almost all the distances from WTE facilities to property do not exceed six kilometers in IBSZ. According to García-Pérez et al. [53], the risk of cancer will increase if there is a hazardous waste facility operating near resident's houses within five kilometers. Hence, families have to pay higher prices to avoid the risks and that is why the depreciation effect in IBSZ far outweighs that in OBSZ. Hence, siting in rural areas can reduce the negative impacts to the largest extent. Since the analysis of other control variables is similar to the results above, they will not be discussed repeatedly for the sake of convenience.

5.1.2. Robust Test of Different Trading Years

After adding the year dummy to the model, the obtained regression results are presented in the middle part of Table 5. Property sample has been divided into 3 groups: the year 2013 group, the year 2014 group and the year 2015 group. Regression was used to explore the impact on the real estate prices posed by the trading year. The results show that the basic model still applies in each trading year. The average property price in 2013 is lower than that in 2014 by 10.45% and lower than that in 2015 by 17.24%, which matches our expectations. Regression coefficients are 0.0089 in 2013, 0.0203 in 2014 and 0.0151 in 2015, which are all significant at the 1% level. Because of few property transactions in 2015 in the sample, the significance of partial control variables in the regression decreased, while the concerned variables are still significant. Regression results confirm that depreciation effects obviously exist in all years, which indicates that local residents show concern about the proximity of WTE plants to their property in different trading years.

Table 5. Robust analysis of hedonic pricing model.

Sample	Whole City	Different Regions		2013–2015	Different Trading Years			Different Distance Intervals	
		IBSZ	OBSZ		2013	2014	2015	0–5 km	0–10 km
Constant	9.3403 *** (0.0562)	9.1902 *** (0.0806)	10.0132 *** (0.1103)	9.4336 *** (0.0572)	9.2090 *** (0.1230)	9.3645 *** (0.0708)	9.5637 *** (0.1678)	9.6289 *** (0.1650)	9.4528 *** (0.0614)
LULU distance	0.0164 *** (0.0014)	0.0310 *** (0.0034)	0.0107 *** (0.0016)	0.0172 *** (0.0013)	0.0089 *** (0.0027)	0.0203 *** (0.0018)	0.0151 *** (0.0045)	0.0861 *** (0.0114)	0.0169 *** (0.0028)
IBSZ	0.1443 *** (0.0203)			0.1569 *** (0.0198)	0.1023 *** (0.0368)	0.2023 *** (0.0286)	0.1189 * (0.0699)	0.4567 *** (0.0505)	0.0957 *** (0.0207)
Y2013				−0.1724 *** (0.0191)				−0.1217 *** (0.0358)	−0.1689 *** (0..0205)
Y2014				−0.0680 *** (0.0178)				−0.0579 *** (0.0327)	−0.0612 *** (0.0194)
Other control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES
N	2119	1260	859	2119	619	1333	167	670	1763
Adj R-sq	0.7667	0.6112	0.6515	0.7793	0.7402	0.7870	0.8574	0.8228	0.7879

Note: * $p < 0.1$, *** $p < 0.01$; the numbers in parentheses indicate the standard error. The results in each column are based on different sizes of samples. The left three columns pertain to regions, the middle four columns represent the regression in different trading years, and the right two column considers different distance intervals. For brevity, the results of control variables are not listed in the table.

5.1.3. Robust Test of Different Distance Intervals

Considering that the negative externality caused by WTE plants may not be constant, the right part of Table 5 shows the regression results in different distance intervals. Intuitively speaking, the farther away from the plants, the fewer depreciation effect the property may suffer. Results meet the expectations and all achieve 1% level of significance. The effect within 5 km rises to 8.6%, which means an additional kilometer away from the plant makes the housing price increase by 8.6%. Interestingly, in the interval 0–10 km, the coefficient of the LULU distance diminishes again, only 1.69%, which is close to the results for the regression of the full sample. Thus, at a farther distance, property values are more affected by other attribute variables. Significant and magnified negative impacts on property values exist in the interval 0–5 km. As a matter of fact, residents truly show concern about WTE plants near their houses, but a sufficient distance may ease concerns. The coefficient of IBSZ increases, to about 0.4567. The sharp increase indicates that the property in IBSZ dramatically pushes up the values within a range of 5 km away from WTE plants. As mentioned above, IBSZ has intensive land resources with a dense population; thus, in comparison to OBSZ, IBSZ still has higher housing demand even in the area near WTE plants. Besides, most distances from WTE facilities to properties do not exceed six kilometers in IBSZ but can reach 10 km in OBSZ. Consequently, the appreciation effect of regions weakens over longer distance intervals.

Based on almost 5 times the negative externality caused by WTE plants within 5 km, more attention should be paid to these areas. This also verifies the conclusion that the policy maker should take the interest of all parties into account. Solving the problem that few residents live near the plants underlies almost all negative externality is quite important because it is a matter of social equity and promotion of WTE technology.

5.2. Analysis of Regression Error

A table on error analysis is represented here. Using the regression in Section 5.1.2 for all variables, the results show the mean error is -3.56×10^{-11} while the median is -0.0021. The variance is 0.0460, the skewness is -1.7786, and kurtosis is 22.2559.

5.3. Cross-Term Regressions

In order to further study whether the depreciation effects generated by WTE plants can be affected by other variables, cross-term regression was studied. The cross-terms consist of the LULU distance with property locations, average housing area, and trading year. Admittedly, there is a gap in economic development between OBSZ and IBSZ. While purchasing property, the different income and risk perceptions of residents will lead to different MWTP for living away from WTE plants. To begin with, studying the impacts of the plants in the two regions on local property values has policy implications for facility siting. Secondly, adding the cross-term concerning property area is used to evaluate whether the scales of houses have marginal contributions to the original results. Finally, concerning the trading year, more attention is paid to how the negative impacts on real estate vary over time. Regression models are defined as follows: $D \times H_i$ represents the respective cross-term of the LULU distance with the above three variables. Therefore, the residents' MWTP becomes $\beta_1 + \beta_5 \times H$.

$$LnP = \beta_0 + \beta_1 D + \beta_2 X_i + \beta_3 Y_i + \beta_4 Z_i + \beta_5 D \times H_i + \varepsilon \quad (5)$$

After adding the cross-terms regarding Dis × IBSZ (IBSZ is a dummy variable that represents the region on the border of Shenzhen city. Equal to 1 means that the property is located on the border of Shenzhen city), the result proves that the property in IBSZ suffers from a greater risk of depreciation. The residents' MWTP to avoid the risk of contamination is 2.75%. Specifically, after controlling other variables, for each additional kilometer away from WTE plants, the price of property in IBSZ will increase higher than that in OBSZ, i.e., by 1.28%. A large difference can be found in these two regions, especially the economic growth. People in IBSZ have to pay more based on results; thus, siting in urban area causes more negative externality. However, in some developed countries, siting in the city center is common. This is not realistic considering the situation in China, and Chinese WTE plants have a long way to go. With constant technology innovation, the public also requires a process of gradual acceptance. Thus, the policy makers should make more effort for scientific site location and to ease NIMBY sentiments.

Based on the investigation about adding the cross-term concerning the LULU distance and property area (Dis × Flo) to the regression, the regression coefficient is −0.00004 and is significant at the 1% level. The result indicates that property with larger area suffers from less decline in prices. The residents' MWTP for each additional square meter of property area is 0.0013. Thus, the price per square meter of property with a large area is significantly higher than that of small houses, let alone the total price. For instance, if the LULU distance increases by 1 km, the price of a 100 square meter house will rise by 1.82% compared with 1.42% for houses of 200 square meters. When real estate is far away from incineration facilities, families' MWTP for living an additional kilometer away from the plants will decrease. It is reasonable to suppose that families select small houses (with lower prices) out of rigid demand and do not have any motivations to pay higher prices to choose property away from WTE plants. However, wealthy families choose property with larger area to improve their living environment. Apparently, these properties are rarely built in the vicinity of the facilities that this paper studies. Therefore, wealthy households reduce the risks of being exposed to hazardous facilities through higher housing prices.

Finally, in the regression including the cross-term of the LULU distance and trading year (Dis × Y2013) in Table 6, the estimated coefficient is 0.15%, but insignificant. A similar regression with the other two years (not listed in the Table 7) was also performed, and the results were insignificant. This sample was selected from 2013 to 2015, while the latest facility was put into operation in 2013. Because the time span of the trading sample belongs to the operational phase, the public that wish to purchase property have already perceived the risk of living near the WTE plants through the media. Although the government has the intention of eliminating the misunderstanding of these facilities through visits and interpretations, NIMBY sentiments still exist. Therefore, the results suggest the depreciation effect will last for a while until the misunderstanding has been eliminated.

Table 6. Cross-term regression in terms of regions, floor area and trading year.

Variables	Dis × IBSZ	Dis × Flo	Dis × Y2013
cons	9.5093 *** (0.0601)	9.4268 *** (0.0572)	9.4354 *** (0.0573)
Dis × IBSZ	0.0128 *** (0.0032)		
Dis × Flo		−0.00004 *** (0.0000)	
Dis × Y2013			0.0015 (0.0025)
LULU distance	0.0147 *** (0.0015)	0.0222 *** (0.0023)	0.0168 *** (0.0015)
IBSZ	0.0927 *** (0.0254)	0.1581 *** (0.0198)	0.1567 *** (0.0198)
Y2013	−0.1697 *** (0.0190)	−0.1749 *** (0.0191)	−0.1827 *** (0.0256)
Y2014	−0.0644 *** (0.0178)	−0.0701 *** (0.0178)	−0.0679 *** (0.0178)
Other control variables	Yes	Yes	Yes
N	2119	2119	2119
Adj R-squared	0.7809	0.7799	0.7792

Note: * $p < 0.1$, *** $p < 0.01$; the number in parenthesis indicates the standard error. Dis*IBSZ, and similar terms indicate the addition of these cross-terms in the regression. The cross-terms for the LULU distance and trading years (2014 and 2015) are not listed in the table. For brevity, the results of control variables are not listed in the table.

Table 7. Error analysis of the hedonic pricing model.

Mean	Median	Variance	Skewness	Kurtosis
-3.56×10^{-11}	−0.0021	0.0460	−1.7786	22.2559

6. Conclusions and Policy Recommendations

With the expanding process of urbanization in China, the municipal solid waste generated from migration has hindered the development of urban civilization and destroyed the living environment of households. In order to address the ever-worsening situation of municipal solid waste, the Chinese government made the decision to promote WTE treatment in 2007. Since then, the technology of WTE has taken a significant leap forward. Although the promotion of WTE facilities has mitigated the problem resulting from MSW, it has also led to some negative effects. The conclusions and estimations from this paper provide important references for government as well as real estate firms.

Firstly, this study proves that the impacts caused by WTE factories have reduced the prices of surrounding properties, and the impacts may be slight from a long distance interval. The basic model indicates that for each additional kilometer away from WTE plants, the average price will increase about 1.30%. When attention is paid to the short distance interval, such as 0–5 km, the appreciation effect can be significantly enlarged, by nearly 8.6%. This indicates that area in proximity to WTE plants suffers more negative externality. Considering the development gap, it is predictable that this value will be larger in other Chinese cities which also possess WTE plants. Meanwhile, the decline in property values in Shenzhen city is mainly caused by residents' lack of sufficient knowledge of these facilities. Sun and Zhu [54] argued that extensive information would help reduce public risk perception and add support for the construction of the facility. Therefore, in order to eliminate misunderstanding of residents, measures should be taken by step and step. First, involving the public in the siting process is important; this can avoid the government's unilateral action and enhance public confidence in the government. Next, carrying out propaganda about high quality plants and interpreting the WTE technology officially can ease public concerns. Besides, promoting waste classification and strengthening monitoring are also crucial because they can reduce the damage of dioxin to the greatest extent. In a word, only when the public truly accepts the WTE plants can the siting suffer fewer protests.

Secondly, this paper compares negative impacts on property values within and outside the border of Shenzhen city caused by the nearby WTE facilities. If the property is located in the IBSZ, the negative effect on housing prices will be significantly increased. For every additional kilometer the property is away from the WTE plants, IBSZ households need to pay more than those in OBSZ, by 1.28%, which indicates that property in IBSZ is more susceptible to local WTE plants. Thus, residents living in this region may show more concern about LULU facilities around their houses. Moreover, the property values in IBSZ within 5 km from the plants are well above those in OBSZ due to the limited land resources and high housing demand. Although the WTE plants in the EU are mostly located in urban areas, there are huge gaps in WTE equipment and supervision between China and European countries. Thus, siting in Chinese urban areas is still not a feasible approach. It is advisable for the government to make tradeoffs between social benefits and regional negative economic impacts. Since siting in the suburbs has significantly smaller negative impacts than in urban areas according to this paper, rural areas are recommended locations. Before the negative externalities are completely eliminated, the government should give subsidies to suburban residents whose property values are affected by local WTE plants.

Last but not least, by introducing the cross-terms, the results confirm that values of property with smaller areas compared to those with larger areas are more likely to reduce when the LULU distance decreases. As a matter of fact, the households with limited income have to select smaller houses, which makes them suffer more from potential risks caused by surrounding WTE plants. Those who prefer property with a larger area succeed in avoiding this risk to a certain degree by paying higher prices. It is also reflected from one side that low-income households would withstand more potential negative externalities posed by WTE plants. Results also show that residents' perception of negative impacts resulting from WTE plants does not significantly increase or decrease over time. If the misconceptions of this technology are still prevalent, the decline in property prices will continue to exist. The government should also guide the public to understand WTE technology correctly in the prerequisite of ensuring the emissions meet the standards. Considering the impacts of different housing characteristics on prices, the results display insight into the preferable attributes as well. Sea view, green rate, in proximity to school, larger floor area and so on can significantly push up the prices. Thus, it provides real estate firms with the necessary information to price the different property. Meanwhile, although urbanization brings higher demand for urban housing, residents' acceptance of property built near WTE facilities also needs to be valued. Making several adjustment in advance for property attributes according to acceptance can develop the market effectively. Of course, the depreciation effects should also be taken into account while setting the price.

Although this paper is the first to study the negative impacts on property values caused by local WTE plants in China, several defects still exist. Firstly, the time span of the selected data is relatively short out of consideration for reducing the price fluctuations (with the policy liberalization of property-purchasing limitations in 2015, the housing price has experienced great fluctuation since then), so it does not include siting, construction and operation phases. For this reason, assessment of the respective impacts on adjacent property values is unable to be obtained for the above periods. Hence, the conclusion pertaining to whether the residents' attitudes towards WTE plants have changed cannot be made. Secondly, because the transaction information of sample property comes from the trading system and has few statistics for homebuyers, this paper has no access to the private information of homebuyers including their profession, attitudes towards WTE plants and so on. Therefore, there will be difficulty in estimating the welfare effects of plants. In order to study the impacts on property prices caused by WTE plants from the perspective of consumer behavior, it is necessary to conduct a survey of households in the target area. Moreover, evaluating how much the seven facilities would influence surrounding property values is the future direction of our research, which is also built on the basis of possessing considerable micro-transaction data. For this purpose, the data needed will be expanded for this paper to meet the requirements of an in-depth study.

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Appendix A

Appendix A.1. Process of Acquiring Data

In order to obtain precise data on research property, the authors searched for the basic information of these properties by means of the SFUN website, including sales status, sold time, prices, locations, plot ratio, the housing area, number of bedrooms, and greening rate. For the facilities surrounding the property, two methods were used to obtain the information: the website was searched to obtain the number of supermarkets, hospitals, bus stations, parks and so on, and we counted the number of facilities on Google maps. We calculated the average to obtain the final data. In order to acquire concerning variables, the linear distance was measured on Google maps. This paper ignored the size of the facilities and property. Moreover, the CDB is located in Futian district, Shenzhen city.

Appendix A.2. Reasons for Choosing Shenzhen as the Sample City

This paper selects Shenzhen as the sample city for two main reasons. Firstly, As China's first special economic zone, Shenzhen's real estate industry experienced the initial reforms. After 30 years of development, it has become one of the four major real estate markets in China, which provides important reference for the formation and development of the national housing market. In addition, as an international city, Shenzhen city possesses many standardized properties equipped with differentiated facilities. The pricing mechanism in Shenzhen city is similar to that in European and American countries, which facilitates our analysis. In addition, due to high urbanization in Shenzhen city, there are sufficient property samples for us to choose from.

Secondly, because of the shortage of land resources and high population density, the waste disposal problems are inevitable in the process of urban development. By the end of 2013, seven WTE plants had been constructed and put into operation in Shenzhen city. Waste incineration capacity is 7875 tons/day, the handling rate is 55%, and the generating capacity is roughly 1.16 billion degrees per year. These indicators rank first in China. Based on the improving real estate market and the emerging WTE technology, it is essential to analyze the impact concerning the LULU distances on property values and then provide advice on the promotion of WTE plants on a large scale.

Appendix A.3. Emission Limits in China

Table A1. Emission limits per day for waste incineration in China.

	GB 2001	Shanghai 2013	GB 2014
Dust (mg/m^3)	80	30	20
CO (mg/m^3)	150 [a]	60	80
NO_x (mg/m^3)	400 [a]	300	200
SO_2 (mg/m^3)	260 [a]	150	80
HCL (mg/m^3)	75 [a]	60	50
Hg (mg/m^3)	0.2	0.05	0.05
Cd+Ti (mg/m^3)	0.1	0.05	0.05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni (mg/m^3)	1.6	0.5	1
Dioxins + furans (mg/m^3)	1	0.1	0.1

Note: GB means the National Standard in China, 2001 presents the promulgation date. Shanghai 2013 is emission limits promulgated by Shanghai Municipal Government in 2013. [a] Represents the mean value per hour.

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