International Journal of Strategic Property Management
ISSN: 1648-715X / eISSN: 1648-9179
2022 Volume 26 Issue 5: 385–396
https://doi.org/10.3846/ijspm.2022.18004

IMPACT OF ACCESS TO SUNLIGHT ON RESIDENTIAL PROPERTY VALUES: AN EMPIRICAL ANALYSIS OF THE HOUSING MARKET IN SHANGHAI

Yi ZHONG[1], Jiajun LU[2], Zhehan LI[3,*]

[1] *College of Economics and Management, China Jiliang University, Hangzhou, China*
[2] *International Business School, Zhejiang University, Haining, China*
[3] *School of Philosophy, Zhejiang University, Hangzhou, China*

Received 05 June 2022; accepted 03 November 2022

Abstract. As an important environmental amenity, sunlight brings us a large number of benefits and improves the quality of our daily lives, and its welfare measurement depends on concrete living conditions. The purpose of this article is to empirically document the non-marketed value of sunlight in light of the view orientation of an apartment in the context of the housing market. Using a hedonic pricing model estimated with the real estate transaction data over 40,000 housing units in 2019–2021 in Shanghai, it is found that: (1) homeowners, on average, are willing to pay an extra 7.2% to choose the apartments with a high level of sunshine (facing south), relative to those with no direct access to sunlight (facing north); (2) the value of sunlight shrinks with pollution and becomes larger if living in a higher apartment; (3) residents living in higher units have a larger willingness to pay for the sunlight and environmental quality improvement. These empirical findings shed light on the welfare measurement of sunlight and have profound implications for the capitalization of environmental amenities reflected in housing prices.

Keywords: environmental amenity, value of sunshine, hedonic pricing, housing market.

Introduction

Sunlight may be considered the most valuable natural resource human beings could employ for free. It is taken more as public good than a private or club good in most cases since it provides inexhaustible power and forms a non-rivalrous situation for the usage (Engerer, 2011). That said, it is critical to put an accurate value on the sunshine since, in some cases, sunlight is still limited in availability. Then, environmental economists should pay more attention to evaluating access to sunlight in some specific context. A prominent example is access to sunshine for residents living at homes, especially for those in big cities. In modern urban cities, residents spend more time indoors, and having direct access to sunlight is strongly preferred. Thus, the attainability of sunlight, which becomes an important environmental amenity for citizens living in large metropolises, becomes of great worth. This goes to the main question this paper plans to answer: how much exactly do homeowners living in cities value access to sunshine. This paper empirically estimates the price premium of the access to sunshine by studying homeowners' purchase behavior in the housing market of Shanghai in China. Specifically, using a hedonic pricing model, new empirical evidence of the value of sunshine is provided by investigating the relationship between the availability of sunshine in apartments and the different expenditures of staying in these housing units.

The starting point relates the project to the strand of research about the hedonic pricing model. Access to sunshine should be considered one of the environmental amenities for attractive apartments. Estimating its value comes from analyzing the trade-off behavior between the availability of sunshine and the higher value it brings. Thus, it is proper to put this project into a line of research about the evaluation of the willingness to pay (WTP) to environmental amenities under the framework of the hedonic pricing method (Rosen, 1974), which is a prominent existing method applied in valuing the non-market good, as the sunlight here in our paper (Ready & Abdalla, 2005; Levinson, 2012). Among them, many studies evaluate non-marketed goods in the context of housing

*Corresponding author. E-mail: *lizhehan@zju.edu.cn*

markets. They employ the hedonic pricing model to estimate the revealed preference towards surrounding environmental goods and thus try to back out the WTP by homeowners. Some estimate how much more residents in cities are willing to pay to live in the area with a higher quality of life, compensated by housing prices and wage differentials (Berger et al., 2008). For instance, Harrison and Rubinfeld (1978), based on the revealed preference of citizens in Boston, examine the value of air quality and calculate the marginal WTP for the less serious air pollution using housing market data. In addition to air quality, some also conduct the research about the hedonic values put on facilities and environmental amenities nearby, such as recreational parks (Poudyal et al., 2009), open space access (Sander & Polasky, 2009), and a scenic view outside the apartments (Jim & Chen, 2009), that impacts the housing price. On top of the surrounding urban amenities, many studies have been conducted by environmental economists to estimate the values of indoor features that matter for quality of life, such as decoration (Chan et al., 2009).

While much research has been done to estimate the hedonic value of various attributes in the context of apartments, very few scholars pay attention to the price of access to sunshine and how it reflects in transaction prices in the housing market. Though it seems difficult to provide direct empirical evidence that people prefer to have sunshine when staying at home, it could bring many benefits to people under the sunshine intuitively.[1] In addition, sunlight might also improve the quality of a scenic view and thus, from the psychological perspective, helps put residents in a better mood. Due to the above-mentioned potential benefits sunlight brings for those living in the apartments, more attention should be paid to price the access to sunshine and estimate its exact value.

Another factor that would impact the value of apartments is the ambient air quality. It is well known that air pollution has become a severe issue in China recently. There have already been many empirical studies that illustrate how air pollution influences people's spending behavior and social welfare (Chen et al., 2013). Citizens, especially in the developed areas, are expected to be more concerned about the severity of air pollution, giving rise to a wide range of avoidance behavior to reduce the air pollution (Zhang & Mu, 2018). Thus, this paper also delves into how the value of access to sunlight varies by air pollution. At last, this paper explores the varying WTPs to sunlight across heights and other housing attributes.

Even if sunlight is considered both environmentally and economically important, no past research, to the best of our knowledge, has ever fully investigated the interrelationship between housing prices and the natural amenity and its interactions with other environmental amenities using the newly available data.[2] To fill the gap, a hedonic pricing model is developed to quantitatively analyze its value using the real estate transaction data of over 40,000 housing units in Shanghai. It is found that: (1) homeowners, on average, are willing to pay extra 3,363 CNY/m^2 (46.32 USD/ft^2) to choose the apartments with direct access to sunlight; (2) the value of sunlight decreases with the pollution level and becomes larger for higher apartments; (3) homeowners living in higher units have a larger willingness to pay for the sunlight and other environmental amenities.

The remainder of this paper is organized as follows. Section 1 describes the literature review. Section 2 briefly summarizes the empirical background and data. Section 3 details the empirical strategies. The empirical results are presented in Section 4. Final section concludes with a summary of key findings and policy implications.

1. Literature review

Our study mainly relates to two strands of literature. The first is an assessment of sunlight's value for residents. View orientation has been vital to the micro-built environment and many buildings have been designed following certain principle of view orientation design in most of the major cities in the world (Mak, 1998). Existing studies have shown that a south-facing orientation is preferred in building design in China (Lip, 1995). The superiority of south-facing views arises from many reasons. Firstly, this preferred view orientation is attributed to one aspect of traditional Chinese culture, Geomancy (Feng Shui). In theories of geomancy, view orientation has always been taken as the foundation of spatial arrangement of the built environment, and due south-facing orientation is given the top priority in the design of residences (Tam et al., 1999). Facing south itself is preferred in many scenarios in Chinese tradition. However, none of these studies have found solid empirical evidence that examines the relevant magnitude, showing the unimportance of Geomancy compared to other critical reasons. Instead, a south-facing view could be preferred due to another more significant benefit, sunlight. All cities in mainland China lie in the northern hemisphere and most of the sunshine comes from the south. In this case, sunlight is more accessible to dwelling units that look south in Shanghai. Moreover, from the psychological perspective, plentiful sunlight may make residents feel more comfortable. Some results show a significant positive effect of sunlight penetration on job satisfaction and general well-being (Leather et al., 1998). In addition, to go along with this intuition, Guven (2012)

[1] For instance, residents could enjoy a very restful afternoon and thus have higher utility by sitting on the balcony under sunlight.

[2] The research work closest to this paper is the paper by Lu (2018) that also empirically estimates the value of south-facing orientation using older transaction data in 2016–2017. Compared to Lu (2018), this paper provides more accurate estimates using more recently available data and a much larger sample size.

employs regional sunshine as an instrument for personal happiness in the Dutch Household Survey and confirms that sunshine generally improves happiness significantly.

On top of the value of sunlight, the findings in this study are also relevant to the hedonic pricing strategy, which involves many studies in this research area. Under the framework of the hedonic pricing method, the estimated value of a southern view comes from the tradeoff between the benefits from a superior view orientation and the higher expenditure paid to attain it (Rosen, 1974; Lancaster, 1979). Many other similar studies have been done regarding the valuation of non-market goods. Some estimate how some attributes in dwellings, e.g., floor level and height, would be reflected in the housing price (Berger et al., 2008; Thanasi, 2016) and how indoor features or apartment design influence the property value (Guntermann & Norrbin, 1987; Chan et al., 2009). Besides the elements in the living space, environmental economists have analyzed how the surrounding environment influences the house value. For instance, many researchers provide the estimated value of ambient air quality improvement in the urban housing market (Harrison & Rubinfeld, 1978; Zhang & Mu, 2018). Some studies give empirical evidence that other environmental amenities, e.g., recreational parks (Poudyal et al., 2009) and open space and scenic views (Jim & Chen, 2009), and urban facilities, e.g., proximity to public transportation (Wang et al., 2016), can also increase the property value and generate a certain premium. Furthermore, using hedonic pricing analysis, the value of access to different kinds of water usage, like irrigation (Faux & Perry, 1999), recreational water (Lansford Jr & Jones, 1995) and drinking water (Des Rosiers et al., 1999) has been estimated.

The hedonic pricing model is also widely adopted in Chinese studies to estimate the valuation of urban amenities in the context of housing market. Some provide the estimated value of urban green space (Kong et al., 2007; Jim & Chen, 2007). Scenic views are considered as desirable environmental amenity that can be priced using hedonic pricing model (Jim & Chen, 2009). Other relevant hedonic pricing studies in Chinese urban area include Mok et al. (1995) and Chen et al. (2013). While much research has been done to estimate the value of apartment attributes and ambient environmental amenities that influence home prices, attention has not been paid to an apartment's view orientation that may also have an impact on housing values, except for Lu (2018) that adopted a much less representative sample data over a remoter period.[3] To fill the gap, this paper provides some empirical evidences about whether and to what extent the preferred view orientation influences an apartment's monetary value while controlling for a wide range of other apartment characteristics.

[3] Lu (2018) estimates the value of south-facing orientation using around 3,000 transaction records over 04/2016 to 04/2017.

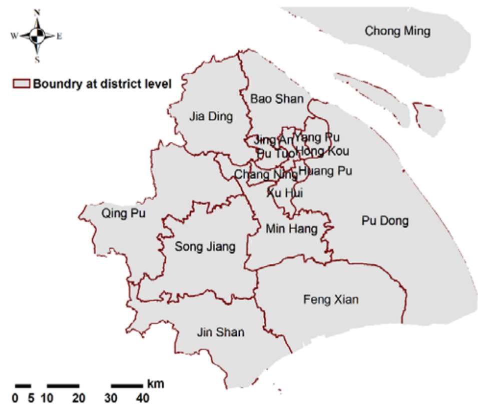
2. Empirical background and data

2.1. Access to sunlight and geography in Shanghai

This paper estimates the non-market value of access to sunshine in the context of Shanghai in China. The availability of sunlight depends mainly on the view orientation of an apartment. As mentioned before, sunlight brings much welfare to people. Potential benefits might be even more significant in large cities such as Shanghai. Citizens living there could relax and enjoy the sunshine by sitting on the balcony while drinking coffee. Another major reason why sunshine is beneficial is that residents are able to dry their clothes through the radiation from the sunlight, which, to some extent, improves the efficiency of housework.[4] Also, arguably, the radiation of sunlight would be critical to keeping the inside warm due to the lack of a heating system in the city of Shanghai during the whole winter. Lastly, some might attribute the south facing and access to sunlight to *Fengshui* (Geomancy), which sounds like a superstitious belief. However, other than that, some also argue that facing the south and sunshine itself is very comfortable and thus preferential in Chinese tradition (Mak & Ng, 2005).

As presented in Panel (a) in Figure 1, the city of Shanghai is located in the northern hemisphere, and thus

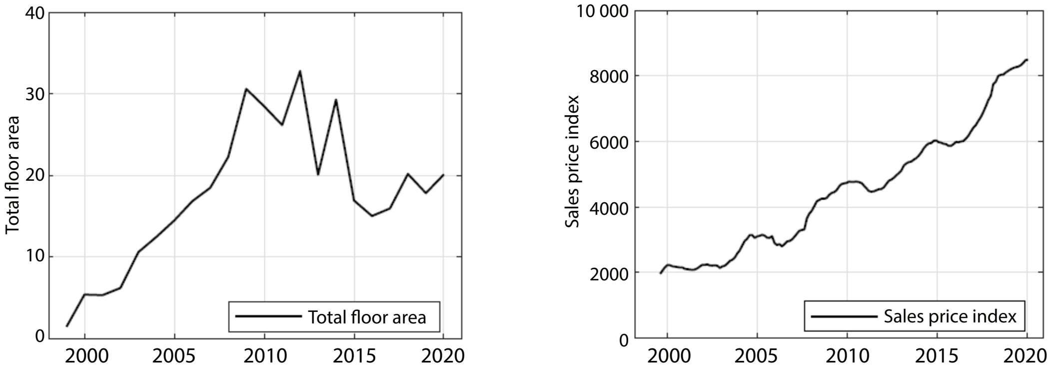
(a) The geographic location of Shanghai



(b) Administritive boundries at district level

Figure 1. Panel (a) shows the city of Shanghai is located in the northern hemisphere, and thus sunlight comes from the south. Panel (b) shows the administrative boundary at district level in Shanghai

[4] People in China usually do not use drying machines that consumes too much electricity. They usually just hang out the clothes on the balcony and let them dry by themselves.



(a) Total floor area (b) Sales price index (CREIS)

Figure 2. Panel (a) shows the annual total floor areas of residential properties sold in million *meter*^{2} over 1998–2020 in Shanghai. Panel (b) shows the monthly sales price index in the second-hand housing market in 1999/01–2019/12 in Shanghai (National Bureau of Statistics of China and China Real Estate Index System, CREIS)

sunshine comes from the south to one building. Overall, if an apartment is facing south, it attains more sunshine on average, and the view orientation influences the amount of sunshine received by each apartment. Combined with the analysis of a view orientation, for most apartments in Shanghai, the benefits of sunshine mainly come from the preferred orientation of the apartments. Therefore, this paper takes the direction of apartments as the proxy for the availability of sunshine.

Panel (b) in Figure 1 illustrates the geographical units of Shanghai, in which there exist a total of 17 administrative districts in Shanghai. Within each district, there are multiple communities as smaller geographical units. Every apartment is classified into one community that belongs to one district.

2.2. The housing market in Shanghai

The total value of a city's housing stock is an important indicator of its prosperity. Due to rapid population growth and economic development, the housing market has skyrocketed in the past decade in Shanghai.[5] Figure 2 shows statistical indices that display a steady and long-lasting growth trend in the Shanghai housing market over the past two decades. Panel (a) in Figure 2 shows that, over the past two decades, the annual total floor area of the residential properties in Shanghai has been increasing drastically in first ten years and gradually drop later until it goes back up recently.[6] Panel (b) in Figure 2 includes the sales price index from the China Real Estate Index System (CREIS)[7]. The sales price index for residential property in the second-hand housing market has increased by almost four times over the past two decades.[8]

2.3. Data construction

The unique dataset assembled in this paper is comprised of three sources, including apartment characteristics, air pollution, and district-level attributes, respectively.

Apartment characteristics: The first category of data source, i.e., apartment characters, are obtained from web-scraping one famous real estate information website named Soufang, on which most of the available private apartments sold in the market are covered.[9] This paper adopts a representative sample of the housing market in Shanghai over 2019–2021 with 40,448 apartments. Housing attributes include sales price, an exact address, view orientation, floor, relative height, decoration type, and year built, which constitutes most of the key factors for an apartment itself. The data in the real estate database of Soufang consist of around 10% of the total sales records in the second-hand housing market and is likely to be reasonably representative of the entire market. The relative height is calculated by dividing the floor of one apartment by the floor of the building in which the unit is located.

[5] Over the past decade, the population in Shanghai has increased by about 50%, from 14.3 million in 2000 to 24.9 million in 2021. Source: https://en.wikipedia.org/wiki/Demographics of Shanghai

[6] Data comes from the National Bureau of Statistics of China. See: http://data.stats.gov.cn/english/

[7] China Real Estate Index System (CREIS) provides monthly reports for China Real Estate Index, including an urban composite index, a house price index, a hedonic index, a resold housing sale price, and a rent index. It is one of the most widely used indices to reflect the monthly housing market trend in China. See: http://fdc.fang.com/index/

[8] The Re-sale price index for residential property in Shanghai was around 2,000 points in 1999 and 8,000 points in 2019.

[9] Soufang holding (NYSE: SFUN) is a publicly-traded company listed on New York Stock Exchange. Fang.com is the website launched by the listed company that provides the real estate data in the housing market of Shanghai. http://sh.fang.com/

Table 1. Summary statistics of key variables in the estimation

Variable	*N*	Mean	Medium	S.D.	Min	Max
Apartment characteristics						
Unit price	40,448	4.6712	4.0066	3.0473	0.5285	46.6505
Eastwest	40,448	0.2378	0	0.4258	0	1
North	40,448	0.0514	0	0.2210	0	1
South	40,448	0.7106	1	0.4535	0	1
Floor	40,448	7.4842	5	6.4726	1	58
Relative height	40,448	0.5763	0.5735	0.2592	0.0303	1
Year built	40,448	2002.25	2004	7.3662	1980	2014
Age of unit	40,448	17.4921	18	8.1721	5	41
Air pollution						
Dust	40,448	5.1582	5	0.6825	3.9	6.9
PM25	40,448	50.6911	51	6.1589	38	67
District attributes						
Population density	51	2.6599	2.0091	1.8906	0.2499	5.4109
Factory	51	8.4932	8	0.4539	2	22
School	51	5.4636	5	0.6096	2	13
Shopping	51	7.6836	6	0.6465	3	15
Hospital	51	3.2946	5	0.2619	3	16
Greenspace	51	3654.22	3360.63	3231.33	390.71	40121.24

Note: The unit price, measured in 10,000 CNY/m^2 represents the total transaction price divided by the area of an apartment. Transaction data of a total of 40,448 housing units and district level yearly averages are collected over 2019–2021. Dust pollution is measured in the unit of tons per squared kilometer, and the concentration of PM2.5 pollution is recorded in the unit of a milligram per cubic meter.

Air pollution: The air pollution data come from the database provided by Shanghai Environmental Protection Bureau on a monthly basis.[10] Among many available data about air pollution, two critical indicators, i.e., dust pollution and PM2.5, are selected since they have the most significant influence on house prices. As the biggest particulate floating in the air, dust pollution would block the light in the air and thus influence the real effect of sunlight on the apartments. The other air pollution indicator chosen in this paper is PM2.5 (particulate matter). It has become the focal point and a recent phenomenon in the discussion of air pollution in China. Many empirical studies have found significant evidence about how the severity of PM2.5 pollution would make people engage in the avoidance behavior more likely and make a defensive investment to reduce their exposure to the particular pollutant. Since PM2.5 has already drawn enough attention from citizens, especially the people living in heavily polluted cities, it becomes important to study whether and the extent to which the pollution impacts the house purchase and how it could interact with the access to sunlight. To measure the pollution level surrounding apartments, we calculate the geometric mean of the district-level indicator in the previous six months and match the numbers with each cross-section.

District attributes: For the district-level character data, this paper employs the yearly data for each district from the Shanghai Bureau of Statistics,[11] including population density, the numbers of schools, shopping malls, hospitals, factories, and green space per capita.

Based on the analysis above, the dataset covers most of the key factors that influence house prices. Table 1 presents the summary statistics of most of the available variables. The variables are divided into two groups, one about apartment characters and the other related to district characters. Table A1 in Appendix details the data sources.

3. Methods

3.1. Baseline model

In a typical hedonic pricing model, the regression equation incorporates the confounding factors when estimating the extent to which an attribute impacts the dependent variable (Rosen, 1974). Controlling for district-level characteristics and other local attributes for apartments, the unit price (transaction price per square meter) is taken as the dependent variable. The view orientation is the variable of interest to elicit the willingness to pay (WTP) for the access to sunshine. The baseline model is presented as follows:

$$\log(Y_{idct}) = \beta_0 + \beta_1 South_i + \beta_2 Rheight_i + \beta_3 Rheight_i^2 + X_i'\Pi + \beta_4 Dust_{dt} + \beta_5 PM25_{dt} + Z_{dt}\Gamma + \delta_c + \lambda_t + \varepsilon_{idct}. \quad (1)$$

where Y_{idct} denotes the unit price of an apartment i in the district d and community c in time t. $South_i$ is the indicator of the view orientation of facing south. $Rheight_i$ represents the relative height of an apartment within the building. X_i and Z_{dt} are two vectors that involve all apartment characteristics and district-level attributes, respectively.

[10] http://www.sepb.gov.cn/fa/cms/shhj/index.html

[11] http://www.stats-sh.gov.cn/index.html

$Dust_{dt}$ and $PM25_{dt}$ denote the levels of dust pollution and PM2.5 pollution. δ_t and λ_t represent the community fixed effects and yearly fixed effects, capturing the unobserved price determinants. ε_{idct} is the idiosyncratic error term. In the regression model (1), a quadratic term of the relative height is introduced to control for the potential nonlinearity in the influence of an apartment's relative height on its value.

3.2. Extended model with heterogeneity

The baseline model presented above assumes that the estimated value of access to sunshine is constant across apartments with varying attributes, such as heights and pollution levels. However, air pollution and height might influence the actual availability of sunshine and its value. Hence, these two restrictions are removed, and the corresponding interaction terms are incorporated to explore the heterogeneous effects of sunlight on property values.

Air pollution × Orientation

The level of air pollution might impact the real availability of sunlight. If the dust pollution becomes more serious, residents would have worse views outside due primarily to the fact that more sunlight has to be blocked by dust floating in the air. Then, the value of sunlight would shrink with air pollution. To control for the potential heterogeneity of the value of access to sunshine by air pollution, the baseline model (1) incorporates the interaction between the orientation and air pollution, i.e., $Dust_{dt} \times South_i$ and $PM25_{dct} \times South_i$.

Relative height × Orientation

The orientation of apartments could influence the access to sunlight, and facing south would put more value on the apartments and be advantageous for those higher units. However, the advantage may also be impacted by another important condition, the height of one apartment relative to its surrounding buildings. In the housing market of Shanghai, real estate developers usually construct buildings of the same height within one community. Thus, this paper adopts the relative height, rather than the absolute height, to measure the amount of sunlight an apartment could receive. In this case, what really matters is the relative height, not absolute height, after controlling for community fixed effect. Due to a larger relative height, an apartment is more likely to have access to the sunshine and thus a better view. Thus, the interaction term, $Rheight_i \times South_i$, is added into the baseline model (1) to examine the relation.

Relative height × Air pollution

In the previous baseline model, it is assumed that air pollution has the same influence on the apartments with different heights. However, it is known that, in terms of the influence on the scenic view, some heavy pollutants, like dust in the air, have a certain maximum level under which most of the pollutants stay. Hence, on some heavily polluted days, some pollution is likely to have different impacts on apartments with varying heights. Therefore, the interactions between the relative height interacts and air pollution, i.e., $Dust_{dct} \times Rheight_i$ and $PM25_{dct} \times Rheight_i$, are included in the hedonic regression equation.

Relative height × Orientation × Air pollution

On top of the above-mentioned heterogeneity, the nonlinearity of overall access to sunshine and air pollution. Therefore, we consider the interaction terms, $Rheight_i \times South_i \times Dust_{dct}$ and $Rheight_i \times South_i \times PM25_{dct}$, in an attempt to analyze the complexity of interdependence among the three factors and their influence on the house prices. The first two items, $Rheight_i \times South_i$, could be taken as the comprehensive indicator of measuring the availability of sunshine. Then, it is measured how the comprehensive indicator interacts with air pollution and thus changes the house price given different levels of air pollution.

According to the analyses above, the heterogeneity of multiple sorts is estimated in the following extended hedonic regression model:

$$\log(Y_{idct}) = \beta_0 + \beta_1 South_i + \beta_2 Rheight_i + \beta_3 Rheight_i^2 + X_i'\Pi + \beta_4 Dust_{dt} + \beta_5 PM25_{dt} + \beta_6 Dust_{dct} \times South_i + \beta_7 PM25_{dct} \times South_i + \beta_8 Rheight_i \times South_i + \beta_9 Dust_{dct} \times Rheight_i + \beta_{10} PM25_{dct} \times Rheight_i + \beta_{11} Rheight_i \times South_i \times Dust_{dct} + \beta_{12} Rheight_i \times South_i \times PM25_{dct} + Z_{dt}\Gamma + \delta_c + \lambda_t + \varepsilon_{idct}, \quad (2)$$

where all other variables are defined the same as before.

4. Empirical results

4.1. Baseline model

Non-spatial models might yield some misleading estimates without controlling for spatial dependence if there exist some spatial autocorrelation in home prices across districts (Kelejian & Prucha, 2001). Before estimating the hedonic pricing models, a Moran's *I* test is conducted for spatial autoregression among home prices across districts, but no spatial effects are found statistically.[12] Thus, this paper reports the estimates mainly by standard hedonic models. Table 2 shows the regression results from the baseline model (1). It is shown in the table that the coefficients on variables of interest, $South_i$, are statistically significant at the 1% level. Compared to other apartments not facing south, apartments facing south, on average, have a higher value of around 7.2% of home prices due to the availability of sufficient sunshine, as analyzed above.[13]

[12] The *p*-value of the Moran's *I* statistic is 0.67, suggesting that we cannot reject null hypothesis in favor of alternative hypothesis.

[13] Some might argue that the price premium of facing-south orientation involves not only sufficient sunshine but also the superstitious belief (Mak, 1998; Tam et al., 1999). However, these studies have found little, if any, solid evidence showing the empirical importance of Geomancy compared to another more significant benefit, sunlight. Thus, the estimates of south-facing orientation could be considered the upper bound of the estimated value of sunlight.

Table 2. The regression results of the baseline model (1)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable: the natural log of a house price per square meter, log (Y_{idct})							
South	0.080***	0.066***	0.067***	0.071***	0.077***	0.072***	0.071***
	(–0.003)	(–0.003)	(–0.003)	(–0.006)	(–0.009)	(–0.002)	(–0.002)
Rheight	2.771***	2.732***	2.932***	2.551***	2.441***	2.516***	2.519***
	(–0.078)	(–0.072)	(–0.073)	(–0.092)	(–0.081)	(–0.057)	(–0.075)
Rheight^2	–1.251***	–1.207***	–1.133***	–1.350***	–1.523***	–1.521***	–1.516***
	(–0.164)	(–0.181)	(–0.157)	(–0.164)	(–0.167)	(–0.15)	(–0.154)
Age	0.072***	0.067***	0.081***	0.075***	0.049***	0.025***	0.026***
	(–0.006)	(–0.006)	(–0.006)	(–0.006)	(–0.006)	(–0.005)	(–0.005)
Area							1.020***
							(–0.015)
PM25		–0.023***	–0.023***	–0.108***		–0.109***	–0.112***
		(–0.007)	(–0.007)	(–0.008)		(–0.013)	(–0.014)
Dust	–0.354***		–0.353***		–0.332***	–0.321***	–0.319***
	(–0.06)		(–0.06)		(–0.068)	(–0.061)	(–0.021)
Pop density				0.910***	0.935***	0.833***	0.831***
				(–0.137)	(–0.143)	(–0.138)	(–0.136)
Factory				–0.060**	–0.022	–0.113**	–0.121**
				(–0.029)	(–0.021)	(–0.05)	(–0.05)
School				0.754***	1.362***	1.216***	1.218***
				(–0.161)	(–0.163)	(–0.156)	(–0.161)
Shopping				0.573***	1.123***	0.234*	0.241*
				(–0.139)	(–0.139)	(–0.134)	(–0.122)
Hospital				2.014***	0.284	3.411***	3.419***
				(–0.46)	(–0.479)	(–0.452)	(–0.422)
Greenspace				0.004***	0.005**	0.006***	0.006***
				(–0.001)	(–0.001)	(–0.002)	(–0.002)
Constant	–1.193***	1.339***	–1.388***	–1.354***	–2.134***	–2.819***	–0.291***
	(–0.171)	(–0.206)	(–0.498)	(–0.729)	(–0.194)	(–0.129)	(–0.012)
District FE	Y	Y	N	N	N	N	N
Community FE	N	N	N	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y
N	40,448	40,448	40,448	40,448	40,448	40,448	40,448
Adjusted R^2	0.239	0.239	0.234	0.372	0.355	0.479	0.421

Note: To control for the potential serial correction with a district, robust standard errors in parentheses are clustered at the district level. For the robustness check, we put area as one of the control variables in column (7), which shows the similar results as before. Thus, we will mainly focus on the unit price as dependent variable. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The estimate is smaller than that in Lu (2018) showing that a south- facing orientation brings a 14% premium in property value. After multiplying the mean unit price of 46,712 CNY/m^2 by 7.2%, the price premium on the sunlight, on average, becomes 3,363 CNY/m^2 (46.32 USD/ft^2) for homeowners in Shanghai.[14]

In addition to the view orientation, both PM2.5 and dust pollution have a negative impact on house prices. Homeowners prefer to live in a high position with a better view outside relative to lower places. Based on the nonlinearity of the relative height for the house prices, another piece of empirical evidence that needs to be pointed out is that, when the relevant height of an apartment is higher, its value becomes first rises and then drops when it reaches the top of the building. It could be attributed to the structure of buildings in Shanghai. Most buildings in Shanghai are equipped with an elevator, thus making it easier for residents living on a higher level. Moreover, living at the bottom is unattractive since it usually is noisier and more humid down below. However, the values of apartment located on the top of buildings are lower relatively since living too high takes more time to get down and thus is less safe in some emergency. Hence, there exists a nonlinear relationship between the relative height and house prices.

[14] The exchange rate is $1.00 = ¥6.745 in 07/2022.

4.2. Extended models

Built upon the baseline model, the hedonic estimation is extended by incorporating the interaction terms to allow varying marginal effects and other complexities. Table 3 shows the regression results of the extended model (2).[15] The coefficient on *Dust* × *South* is significantly negative. Given the positive sign of *South*, it confirms the previous presumption that the value from having an advantageous orientation shrinks with dust pollution. Based on the empirical results about the interaction term *Rheight* × *South*, the positive relation between the marginal effect of facing south and relative height provides significant evidence that the availability and hedonic value of sunshine could be magnified by the height of an apartment. As for the interaction between air pollution and relative height, the empirical evidence indicates that the height would alleviate the negative influence of both PM2.5 and dust pollution on the house prices. It implies that, if you stay in a very high apartment, you are still able to see miles away from where you stand even on heavily polluted days. Dust pollution has a less significant influence than PM2.5 on high apartments. Since the PM2.5 pollution is almost invisible by our naked eyes, its impact on house prices should be identical across the heights. Due to the negative sign of the coefficient on dust pollution in the baseline model before, the positive coefficient of the interaction term makes the total coefficient less negative, resulting in a smaller marginal effect.

Given the ambiguity of the direction of the influence of *Rheight* × *Orientation* × *Airpollution* on the house prices, two presumptions are provided in the analysis. The first presumption is that, as pollution gets more serious, the value of access to sunshine declines (Zhang et al., 2020). It is proper to take the first two items, $Rheight_i \times South_i$, as the comprehensive indicator of measuring the availability of sunshine. We examine how the comprehensive indicator interacts with air pollution and how it changes the house price given different levels of air pollution. The other proposed presumption is that residents living in more expensive apartments are supposed to care more about environmental quality and thus be more responsive to air pollution (Tu et al., 2020). Figure 3 graphically outlines the spatial heterogeneity. Empirically, house prices are higher for those being higher and facing south. People living in section A would have to pay more to purchase the apartment and are more likely to be rich relative to those living in other sections. As people get wealthier, they are willing to pay more to reduce the air pollution (Chay & Greenstone, 2005). Therefore, residents in section A would be more concerned about air pollution. As a result, the negative marginal effect of air pollution would be larger for them, which is reflected in the larger price elasticity to air pollution. However, from the empirical results, we cannot actually see any clear and significant relationship. It might be the case that two types of influence coexist simultaneously and impact the house prices in the opposite ways.

[15] Due to the limited space, only the estimates on variables of interest are shown here, and the complete regression results of the extended model (2) are presented in Table A2 in Appendix.

Table 3. The regression results of the extended model (2)

	(1)	(2)	(3)	(4)
Dependent variable: house price per square meter, log (Y_{idct})				
Rheight × South	0.327***			0.294***
	(0.015)			(0.015)
Rheight × Dust		0.024***		0.021***
		(0.008)		(0.009)
Rheight × PM25		0.031***		0.029***
		(0.006)		(0.007)
Dust × South			–0.352***	–0.323***
			(0.074)	(0.064)
PM25 × South			–0.219***	–0.319***
			(0.065)	(0.064)
Rheight × South × Dust				–0.006
				(0.007)
Rheight × South × PM25				–0.004
				(0.006)
Community FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
N	40,448	40,448	40,448	40,448
Adjusted R^2	0.644	0.643	0.641	0.642

Note: To control for the potential serial correction with a district, robust standard errors in parentheses are clustered at the district level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

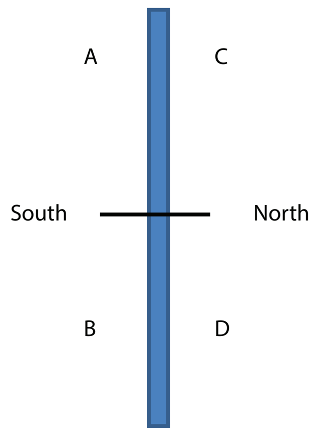


Figure 3. Representation of the orientation and relative height

Conclusions

This paper documents the relationship between the view orientation of dwelling units and their property values and empirically estimate the nonmarket value of sunlight in the Shanghai housing market under a hedonic pricing framework. Using the real estate transaction data of over 40,000 housing units in 2019–2021, empirical results suggest that, other factors being equal, homeowners in Shanghai, on average, are willing to pay extra 3,363 CNY/m^2 (46.32 USD/ft^2) to choose the apartments with sufficient sunlight and orientation facing south, smaller than that in Lu (2018) showing that a south-facing orientation brings a 14% premium in property value. The value of sunlight becomes larger with relative height, suggesting that people living in higher apartments are willing to pay more for south-facing apartments rather than ones in other orientations. It is also found that the price premium of sunlight shrinks with pollution and that dust pollution has a less significant influence than PM2.5 on higher apartments. Moreover, we find that, according to the empirical results of three-variable interactions, people living in high apartments facing the south have a slightly larger willingness to pay for the sunlight if the air quality is improved.

On top of the new findings, there might exist some potential for further improvement in this paper. The estimated value of sunlight potentially gets entangled with the price premium of Geomancy. Admittedly, due to the lack of data on real-time apartment-specific sunlight intensity, the premium effect caused by sunlight is inseparable from that of Geomancy. However, as suggested in the literature review, these studies have found little, if any, solid evidence showing the empirical importance of Geomancy compared to another more significant benefit, sunlight. This makes the issue much less worrying, and the estimates are just slightly upward biased if any. Moreover, exploring the heterogeneity of sunlight's value by air pollution and relative height could provide the unbiased estimated marginal value of sunlight since the value of Geomancy is not very likely to vary by them. Thus, we could take the estimates of south-facing orientation as the upper bound of the estimated value of sunlight.

Sunlight brings us a large number of benefits and improves the quality of our daily lives, and its welfare measurement depends on concrete living conditions. During the ongoing COVID-19 pandemic, many residents in Shanghai have to stay indoors due to a lockdown and thus need sunlight more than ever. Such an unusual scenario could raise the value of sunlight and reinforces its importance for potential homeowners in the housing market. Furthermore, real estate developers would also find the estimates useful since they need them to help develop the best pricing strategy based on the apartment attributes. Lastly, understanding the hedonic value of different view orientations and their interaction with different environmental and urban amenities is also important for a wide range of city planning purposes. This paper sheds light on the welfare measurement of sunlight and has profound implications for the capitalization of environmental amenities reflected in housing prices.

Acknowledgements

Authors acknowledge the financial support from the Zhejiang Provincial Philosophy and Social Sciences Planning Project.

Funding

This work was supported by Zhejiang Provincial Philosophy and Social Sciences Planning Project (23NDJC078YB).

Author contributions

Y. Zhong carried out the conceptualization and methodology. J. Lu finished the original draft preparation and writing, as well as the funding acquisition. Z. Li conducted the review and editing of the manuscript. All authors read and approved the final manuscript.

Disclosure statement

The authors declare no potential conflicts of interest with respect to the research, authorship, and publication of this article. This article does not contain any studies involving human participants performed by any of the authors.

References

Berger, M. C., Blomquist, G. C., & Peter, K. S. (2008). Compensating differentials in emerging labor and housing markets: estimates of quality of life in Russian cities. *Journal of Urban Economics*, *63*(1), 25–55. https://doi.org/10.1016/j.jue.2007.01.006

Chan, E., Yim Yiu, C., Baldwin, A., & Lee, G. (2009). Value of buildings with design features for healthy living: a contingent valuation approach. *Facilities*, *27*(5/6), 229–249. https://doi.org/10.1108/02632770910944952

Chay, K. Y., & Greenstone, M. (2005). Does air quality matter? Evidence from the housing market. *Journal of Political Economy*, *113*(2), 376–424. https://doi.org/10.1086/427462

Chen, Y., Ebenstein, A., Greenstone, M., & Li, H. (2013). Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. *Proceedings of the National Academy of Sciences*, *110*(32), 12936–12941. https://doi.org/10.1073/pnas.1300018110

Des Rosiers, F., Bolduc, A., & Thériault, M. (1999). Environment and value Does drinking water quality affect house prices? *Journal of Property Investment & Finance*, *17*(5), 444–463. https://doi.org/10.1108/14635789910294877

Engerer, H. (2011). Security as a public, private or club good: some fundamental considerations. *Defence and Peace Economics*, *22*(2), 135–145. https://doi.org/10.1080/10242694.2011.542333

Faux, J., & Perry, G. M. (1999). Estimating irrigation water value using hedonic price analysis: a case study in Malheur County, Oregon. *Land Economics*, *75*(3), 440–452. https://doi.org/10.2307/3147189

Guntermann, K. L., & Norrbin, S. (1987). Explaining the variability of apartment rents. *Real Estate Economics*, *15*(4), 321–340. https://doi.org/10.1111/1540-6229.00435

Guven, C. (2012). Reversing the question: does happiness affect consumption and savings behavior? *Journal of Economic Psychology*, *33*(4), 701–717. https://doi.org/10.1016/j.joep.2012.01.002

Harrison, D., & Rubinfeld, D. L. (1978). Hedonic housing prices and the demand for clean air. *Journal of Environmental Economics and Management*, *5*(1), 81–102. https://doi.org/10.1016/0095-0696(78)90006-2

Jim, C. Y., & Chen, W. Y. (2007). Consumption preferences and environmental externalities: a hedonic analysis of the housing market in Guangzhou. *Geoforum*, *38*(2), 414–431. https://doi.org/10.1016/j.geoforum.2006.10.002

Jim, C. Y., & Chen, W. Y. (2009). Value of scenic views: hedonic assessment of private housing in Hong Kong. *Landscape and Urban Planning*, *91*(4), 226–234. https://doi.org/10.1016/j.landurbplan.2009.01.009

Kelejian, H. H., & Prucha, I. R. (2001). On the asymptotic distribution of the Moran I test statistic with applications. *Journal of Econometrics*, *104*(2), 219–257. https://doi.org/10.1016/S0304-4076(01)00064-1

Kong, F., Yin, H., & Nakagoshi, N. (2007). Using GIS and landscape metrics in the hedonic price modeling of the amenity value of urban green space: a case study in Jinan City, China. *Landscape and Urban Planning*, *79*(3), 240–252. https://doi.org/10.1016/j.landurbplan.2006.02.013

Lancaster, K. (1979). *Variety, equity, and efficiency: product variety in an industrial society*. Columbia University Press. https://doi.org/10.7312/lanc94538

Lansford Jr, N. H., & Jones, L. L. (1995). Recreational and aesthetic value of water using hedonic price analysis. *Journal of Agricultural and Resource Economics*, *20*(2), 341–355.

Leather, P., Pyrgas, M., Beale, D., & Lawrence, C. (1998). Windows in the workplace: sunlight, view, and occupational stress. *Environment and Behavior*, *30*(6), 739–762. https://doi.org/10.1177/001391659803000601

Levinson, A. (2012). Valuing public goods using happiness data: the case of air quality. *Journal of Public Economics*, *96*(9–10), 869–880. https://doi.org/10.1016/j.jpubeco.2012.06.007

Lip, E. (1995). *Feng Shui: environments of power: a study of Chinese architecture*. John Wiley & Son Ltd.

Lu, J. (2018). The value of a south-facing orientation: a hedonic pricing analysis of the Shanghai housing market. *Habitat International*, *81*, 24–32. https://doi.org/10.1016/j.habitatint.2018.09.002

Mak, M. Y. (1998). Application of Feng Shui principles to major cities in the world. In G. Baird & W. Osterhaus (Eds.), *Science and design* (pp. 83–89). Victoria University of Wellington.

Mak, M. Y., & Ng, S. T. (2005). The art and science of Feng Shui: a study on architects' perception. *Building and Environment*, *40*(3), 427–434. https://doi.org/10.1016/j.buildenv.2004.07.016

Mok, H. M. K., Chan, P. P. K., & Cho, Y.-S. (1995). A hedonic price model for private properties in Hong Kong. *The Journal of Real Estate Finance and Economics*, *10*(1), 37–48. https://doi.org/10.1007/BF01099610

Poudyal, N. C., Hodges, D. G., & Merrett, C. D. (2009). A hedonic analysis of the demand for and benefits of urban recreation parks. *Land Use Policy*, *26*(4), 975–983. https://doi.org/10.1016/j.landusepol.2008.11.008

Ready, R. C., & Abdalla, C. W. (2005). The amenity and disamenity impacts of agriculture: estimates from a hedonic pricing model. *American Journal of Agricultural Economics*, *87*(2), 314–326. https://doi.org/10.1111/j.1467-8276.2005.00724.x

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. *Journal of Political Economy*, *82*(1), 34–55. https://doi.org/10.1086/260169

Sander, H. A., & Polasky, S. (2009). The value of views and open space: estimates from a hedonic pricing model for Ramsey County, Minnesota, USA. *Land Use Policy*, *26*(3), 837–845. https://doi.org/10.1016/j.landusepol.2008.10.009

Tam, C. M., Tso, T. Y. N., & Lam, K. C. (1999). Feng Shui and its impacts on land and property developments. *Journal of Urban Planning and Development*, *125*(4), 152–163. https://doi.org/10.1061/(ASCE)0733-9488(1999)125:4(152)

Thanasi, M. (2016). Hedonic appraisal of apartments in Tirana. *International Journal of Housing Markets and Analysis*, *9*(2), 239–255. https://doi.org/10.1108/IJHMA-03-2015-0016

Tu, M., Zhang, B., Xu, J., & Lu, F. (2020). Mass media, information and demand for environmental quality: evidence from the "Under the Dome". *Journal of Development Economics*, *143*, 102402. https://doi.org/10.1016/j.jdeveco.2019.102402

Wang, Y., Feng, S., Deng, Z., & Cheng, S. (2016). Transit premium and rent segmentation: a spatial quantile hedonic analysis of Shanghai Metro. *Transport Policy*, *51*, 61–69. https://doi.org/10.1016/j.tranpol.2016.04.016

Zhang, C., Shen, C., Yang, Q., Wei, S., Lv, G., & Sun, C. (2020). An investigation on the attenuation effect of air pollution on regional solar radiation. *Renewable Energy*, *161*, 570–578. https://doi.org/10.1016/j.renene.2020.07.146

Zhang, J., & Mu, Q. (2018). Air pollution and defensive expenditures: evidence from particulate-filtering facemasks. *Journal of Environmental Economics and Management*, *92*, 517–536. https://doi.org/10.1016/j.jeem.2017.07.006

Appendix

Table A1. Definition and description of variables in hedonic equations

Variable	Definition and explanation	Data source
Apartment attributes		
View orientation	There are in total of ten possible view orientations for one unit. For example, south implies one apartment has only the south view and south-north means this dwelling unit has both the north and south views	Sofun database
Address	Detailed addresses are transformed into latitude and longitude in ArcGIS	Sofun database
House price	The sales price for dwellings in the database, priced in CNY	Sofun database
Total floor area	The floor area of each dwelling in units of square meter	Sofun database
Floor level	The number of floor on which one unit is located in the building	Sofun database
Stories of building	The total stories in the building where one unit is located	Sofun database
Interior decoration	It is classified as three types, no decoration (reference), partial decoration and complete decoration	Sofun database
Year built	It indicates the year when the unit is built	Sofun database
Time sold	It is the time one residence is sold on a daily basis	Sofun database

End of Table A1

Variable	Definition and explanation	Data source
Air quality		
Dust pollution	Weight of dust pollution, in unit of ton per square kilometer	SEPB
PM2.5 pollution	Concentration of PM2.5 pollution, in unit of milligram per cubic meter	SEPB
Weather		
Temperature	The city's average temperature in Fahrenheit on a daily basis	NOAA
Dew point	The city's average dew point in Fahrenheit on a daily basis	NOAA
Sea level pressure	The city's average pressure in hPa on a daily basis	NOAA
Humidity	Daily likelihood of precipitation (%)	NOAA
Wind	Daily average wind speed, miles per hour (MPH)	NOAA
Sunny day	The number of sunny days in a given period	NOAA
Urban spatial structure		
District	There are a total of 16 districts in the city and my sample data cover 15 of them	SBS
Subdistrict	There are a total of 214 subdistricts in the city	SBS
View	Discrete variable that indicates how many attractions one unit could have the views of	SMTA
Distance	The linear distance in meters between attraction and unit. It becomes average distance if it has several views	SMTA

Table A2. The complete regression results of the extended model (2)

	(1)	(2)	(3)	(4)
Dependent variable: house price per square meter, log (Y_{idct})				
South	0.067***	0.071***	0.077***	0.072***
	(0.003)	(0.006)	(0.009)	(0.002)
Rheight South	0.327***			0.294***
	(0.015)			(0.015)
Rheight × Dust		0.024***		0.021***
		(0.008)		(0.009)
Rheight × PM25		0.031***		0.029***
		(0.006)		(0.007)
Dust × South			–0.352***	–0.323***
			(0.074)	(0.064)
PM25 × South			–0.219***	–0.319***
			(0.065)	(0.064)
Rheight × South × Dust				–0.006
				(0.007)
Rheight × South × PM25				–0.004
				(0.006)
Rheight	1.932***	1.552***	1.433***	1.522***
	(0.073)	(0.092)	(0.076)	(0.061)
$Rheight^2$	–1.133***	–1.350***	–1.531***	–1.532***
	(0.157)	(0.164)	(0.167)	(0.150)
Age	0.081***	0.072***	0.047***	0.026***
	(0.006)	(0.006)	(0.006)	(0.005)
PM25	–0.023***	–0.108***	–0.111***	–0.121***
	(0.006)	(0.007)	(0.008)	(0.013)
Dust	–0.354***	–0.353***	–0.331***	–0.323***
	(0.060)	(0.060)	(0.068)	(0.061)
Pop density	0.807***	0.914***	0.932***	0.831***
	(0.124)	(0.137)	(0.143)	(0.138)

End of Table A2

	(1)	(2)	(3)	(4)
Factory	-0.030^{***}	-0.061^{**}	-0.024	-0.121^{**}
	(0.009)	(0.029)	(0.021)	(0.050)
School	0.643^{***}	0.751^{***}	1.359^{***}	1.221^{***}
	(0.034)	(0.161)	(0.163)	(0.156)
Shopping	0.235^{***}	0.573^{***}	1.132^{***}	0.241^{*}
	(0.131)	(0.141)	(0.139)	(0.134)
Hospital	1.743^{***}	2.014^{***}	0.256	3.411^{***}
	(0.455)	(0.460)	(0.479)	(0.452)
Greenspace	0.003^{*}	0.004^{***}	0.005^{**}	0.006^{***}
	(0.002)	(0.001)	(0.001)	(0.002)
Community FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
N	40,448	40,448	40,448	40,448
Adjusted R^2	0.644	0.643	0.641	0.642

Note: To control for the potential serial correction with a district, robust standard errors in parentheses are clustered at the district level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.