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ASSESSING THE ECONOMIC PREMIUM OF ADDITIONAL ELEVATOR: PSM HEDONIC ANALYSIS IN BEIJING, CHINA

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Abstract. Although many Chinese cities have made remarkable progress in promoting age-friendly housings, few empirical studies related to the premium price of housings with additional elevators installed have been reported. In this study, we constructed propensity score matching–hedonic price models as well as quantile–hedonic models to assess the impact of adding elevators on housing prices. This study concludes: (1) The impact of additional elevators on housing prices varies depending on the floor level. (2) Single-facing and older housings are more likely to be negatively affected by the addition of elevators, and this interaction increases with floor level. (3) Adding an elevator reduces the price of low-priced housings on low floors and raises the price of high-priced housings on low floors, while for middle-floor and high-floor housings, the premium increases with the price of the housing. (4) Compared with the commercial community housings, the elevator premium of the affordable community housings is higher. Our findings provide an important reference for local governments to formulate appropriate charging and compensation mechanisms for adding elevators to multistory housings to promote retrofitting of aging communities.

Keywords: age-friendly retrofit, additional elevator, housing price, floor level, affordable community.

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1. Introduction

Compared with young and middle-aged people, the mobility of the elderly is limited, and the lack of elevators in multistory buildings has become a major health obstacle for the elderly (Chen et al., 2023). Therefore, elevator installation is an important part of age-friendly community retrofits (Yang & Li, 2023). The Chinese government has put enormous effort into promoting and installing elevators in multistory buildings, and "installing elevators" has been included in the State Council's government work report for five consecutive years since 2018. Though various regional governments in China have made great efforts to develop the project of adding elevators to existing residential buildings, the actual process remains far from the policy goal. The implementation of the work of installing elevators in old neighborhoods has been hindered by reasons related to fund-raising, cost-sharing, approval procedures, operation, and supervision, among others (Ning, 2014). However, according to the interviews conducted by this research group in Beijing with residents, communities, streets, and staff of the government departments in charge, the greatest difficulty in installing elevators is the development of the charging and compensation mechanism for installing elevators, which cannot be separated from the discussion on the premium for installing elevators (Liu & Sun, 2019).

The hedonic price model suggests that the price of a housing is determined by a set of features of the housing, which combine to form a package of features that affect the price of the housing (Tsai, 2022). Compared with multistory housings without elevators, those with elevators are favored by most prospective buyers due to their convenient travel characteristics, and these buyers show a higher willingness to pay (Dai et al., 2022). The economic benefits brought by this willingness to pay make the elevator configuration of multistory housings one of the features determining the price of housings, which pushes up the price of multistory elevator houses (Ma et al., 2022). In recent years, many scholars at home and abroad have explored the impact that the addition of elevators to multistory houses has brought to the lives of residents and housing prices based on the perspectives of case studies (Liu & Sun, 2019) and qualitative discussions (Zhou & Tang, 2019). However, few studies have quantitatively analyzed the economic premium of the addition of elevators based on the hedonic price model.

To that end, we sought to answer the following questions: First, will the provision of additional elevators change the floor structure of housing prices? In other words, compared with high-floor flats, can middle-floor and low-floor flats without elevators be sold at higher prices due to their convenient traveling characteristics? After the addition of elevators, will people's preference for different floors change due to the disappearance of the convenience of the middle and low floors? What kind of impact does the addition of elevators have on the prices of residential units on different floors? Second, are there any negative externalities associated with the installation of elevators? Does it have a negative impact on housing prices due to the impact on safety, noise, lighting and ventilation? Third, is the premium for adding elevators consistent across price levels and types of communities?

To answer the above questions, we took Beijing as an example for empirical analysis. Beijing, the capital of China, is the first city to promote the installation of additional elevators in multistory houses, which lays the foundation for the study. We constructed a propensity score matching and hedonic price model (PSM–hedonic model) as well as a quantile–hedonic model to assess the impact of adding elevators on the price of multistory housings. Our study adds to existing research in three ways. First, we are among the first to explore the economic premium of adding elevators, which is valuable for governments and planning authorities to formulate effective promotion programs for age-friendly housing to facilitate the development of community-based aging-in-place models. Second, our study comprehensively explains the negative externalities of adding elevators. Specifically, it answers whether adding an elevator affects safety, noise, lighting and ventilation, which in turn affects housing prices. Third, while past studies on the factors affecting housing prices have focused on a particular aspect of commercial (Cai & Gao, 2022) or affordable (Ma et al., 2018) community housing, we discuss the premium for adding elevators in commercial and affordable community housing through market segmentation and quantile regression models. This not only captures the potential differences between the two markets due to different consumer preferences but also provides a systematic assessment of the economic premium for adding elevators to housings at different price levels (Wen et al., 2022).

2. Literature review and research hypotheses

Many studies have used "floor", the floor number, as a control variable to explore the impact of other factors on housing prices (Hui et al., 2018; Zhang et al., 2019). However, there are fewer studies based on the impact of the floor itself on housing prices. A few research groups have assessed the impact of floor on housing price from the perspective of a linear relationship and concluded that housing price increases with higher floors, proving the premium effect of high floors (Khiew & Lee, 2019). With the popularity of high-rise buildings and the gradual deepening of research related to housing prices, scholars have begun to explore the impact of floors on housing prices from the perspective of a non-linear relationship (Chau et al., 2001). For instance, Xiao et al. (2019) analyzed the floor premium of multistory and high-rise residential transactions in Hangzhou using quadratic regression and observed that for both multistory and high-rise housings, the impact of floors on the price of housings was inverted U-shape, and the middle floors had the greatest enhancement in the price of housings.

While these studies have enriched the understanding of floor premiums, they have neglected the effect of elevators on floor premiums (Hwang & Ma, 2023). The mechanism by which floors affect housing prices is complex and is essentially determined by two aspects: living environment and travel convenience (Conroy et al., 2013). On the one hand, higher floors can bring a broader view and better ventilation and lighting (Hui et al., 2012), and along with higher floors, noise (Wen et al., 2020), mosquitoes (Belcher & Chisholm, 2018), humidity (Xiao et al., 2019), and air pollution (Li et al., 2021) can also be reduced to a certain extent. These positive externalities of higher floors allow residents to have a better living experience. On the other hand, for multistory houses without elevators, high floors limit the daily travel of residents, especially the elderly (Wu & Ouyang, 2017). Yu et al. (2020) based their study on the travel intentions of the elderly living in multistory houses without elevators in Shanghai and found that for every higher floor, the willingness of the elderly to climb the stairs for outdoor activities decreases by one-third. In multistory housings without elevators, the vertical barrier increases gradually from the first to the seventh floor, and residents living on higher floors need to climb more stairs to reach the outdoor environment. Thus, the travel cost of higher floors affects the floor premium when shopping for housings without elevators (Lyu et al., 2021). Considering the negative externality of higher floors in terms of increased travel costs, elevator configuration can compensate for the disadvantage of higher floors without elevators, impacting housing prices (Chen et al., 2022). Based on this, we hypothesized the following:

H1: Adding an elevator generates a heterogeneous premium across floors, which leads to changes in the effect of floors on housing prices.

Lighting affects residents' home-buying decisions. Fleming et al. (2018) examined the Wellington residential transaction data and found that for every hour increase in a housing's light hours, the price of the housing increased by 2.6%. While floor and orientation are two of the most important factors affecting housing prices, housings with high floors and southern orientation tend to have more light (Lu, 2018). The addition of an external elevator will affect the light and ventilation of a housing to a certain extent due to the obstruction it causes to the windows. This effect is particularly significant for single-facing housings with only one side of light and has a more pronounced effect on the price of their housings. Based on this, we formulated our second hypothesis:

H2: The economic premium for adding an elevator is influenced by orientation.

In addition to the impact on lighting, the building safety and noise problems caused by the addition of elevators have also raised concerns among residents. Although the additional elevator is configured outside the building and does not change the original structure of the building, the act of digging and filling the foundation and arranging the steel frame in the construction of the elevator has brought negative impacts such as rainwater seepage to some of the buildings, especially the old buildings (Guo et al., 2019). Besides, every elevator needs a winch, and in the original elevator room, the winch is located on the N+1 floor, which is an independent floor and has no effect on the residential floors. However, in the additional elevator buildings, due to the initial design did not reserve the space for the winch, and thus the winch is often installed on the top floor, causing great noise nuisance to the residents of the upper floors, which is also a more serious impact on the thin walls of the older building (Zhou & Tang, 2019). Based on this, we formulated our third hypothesis:

H3: The economic premium for adding an elevator is influenced by age.

Studies have demonstrated that buyers of low-priced housings place a higher value on features that satisfy their basic needs, while buyers of medium and high-priced housings express a higher willingness to pay for "life-enhancing" amenities (Wen et al., 2019). Adding an elevator, as one such life-enhancing amenity, is to some extent preferred by buyers of medium and high-priced housings. Additionally, high-priced housings are often located in communities with lower plot ratios, where installing elevators has a limited impact on light and ventilation due to the distance between buildings (Lai et al., 2013). On the contrary, low-priced housings are often located in densely built-up communities with high plot ratios, and there is even the phenomenon of "handshake buildings", in which ventilation and lighting are generally poorer (Higgins, 2019). Therefore, installing elevators in low-priced housings may deprive residents of sunlight, which is already scarce, and cause opposition from residents. In light of this, we put forward our fourth hypothesis:

H4: The economic premium for adding an elevator varies across the conditional distribution of housing prices.

Relevant studies have shown that there exists a difference in the preferences of home-buyers for investment purposes and home-buyers for residential purposes and that home-buyers for investment purposes tend to express a higher willingness to pay for life-enhancing facilities, so that these facilities, such as the addition of elevators, have a stronger impact on the investment value of housings (Wen et al., 2021). The liquidity of housing in the real estate market affects its investment value (Lai et al., 2017). Compared with commercial housing, the liquidity of affordable housing in the trading market is weaker, which limits its investment value, and the willingness to pay for life-enhancing facilities of affordable housing buyers tends to be lower (Yang et al., 2014).

Reportedly, there are more elderly or disabled people with mobility problems in affordable housing communities than in ordinary commercial housing communities, and the demand for additional elevators and other accessibility features is also stronger (Gu et al., 2020). For these groups, the installation of additional elevators is a residential feature that meets basic living needs and greatly affects the use value of the housing, for which they tend to express a higher willingness to pay. This contradictory viewpoint leads to the fact that we cannot accurately assess the difference in the premium for additional elevators between affordable and commercial housing communities solely through the community segmentation of these two kinds of communities. While the use and investment value of housings in different price segments exert varying degrees of influence on the price of housings, in general, buyers of low and medium-priced housings are more concerned about the use value of housings, while buyers of high-priced housings are more concerned about the investment value of housings (Wen et al., 2021). Therefore, it is important to account for the differences in preferences for adding an elevator between community-type and housing price segments to discuss the use and investment value of adding an elevator separately. Based on this, we put forward our fifth hypothesis:

H5: There is a difference in elevator premiums between affordable housing communities and commercial housing communities, and this difference varies with the conditional distribution of housing prices.

3. Case study, data, and method

3.1. Case study

Beijing, as the capital of China, is often one of the first pilot cities in which various policies are tried and promoted, and it is also one of the cities in China with a high degree of aging (Z. Liu et al., 2022). The Seventh National Population Census shows that the elderly population aged 60 years and above is 4,416,000, accounting for 20.18%, and the elderly population aged 65 years and above is 3,116,000, accounting for 14.23% (Akimov et al., 2021). To cope with the pension pressure brought by the aging population, Beijing has vigorously developed age-friendly buildings and communities. In 2016, Beijing issued the "Implementation of the Pilot Program for the Addition of Elevators to Existing Multi-storey Dwellings in Beijing in 2016", which started a pilot program to add elevators to existing dwellings. In 2020, Beijing issued a Residential Design Code that requires newly built dwellings of four floors and above to be equipped with elevators. Since promoting old neighborhoods to install elevators in 2016, Beijing has started a total of 2,212 elevators, completed their installation, and put into use 1,462 elevators. While Beijing currently has 2.37 million units without elevators on the 4–6 floors, the existing number of additional elevators is insufficient. Compared with other pilot cities for the retrofitting of elevators in old neighborhoods, Beijing has the advantages of early retrofitting work, strong government support, and a deep public understanding of the policy, which lays a solid foundation for our study, which is why we chose Beijing as a case city for the study.

3.2. Data and variable description

The research data described herein were acquired from Lianjia's second-hand real estate transaction website. As an intermediary organization with over 50% market share of second-hand housing in Beijing, Lianjia's second-hand housing transaction records are highly comprehensive and representative. The transaction time is limited to March 2017 to March 2021 after the first additional elevators started to be put into use. The database contains information such as housing price, area, age, decoration status, floor, and orientation. According to the policy related to the additional elevator and the original elevator in Beijing, the data of the total floor height of 4–7 floors were retained, and based on the related literature, 1–2 floors were defined as "low floor", 3–4 floors were defined as "middle floor", and 5–7 floors were defined as "high floor" (Ma et al., 2022). Subsequently, the POI geographic information data were used to mine the residential neighborhood characteristics and location characteristics to determine the variables such as transportation facilities, educational facilities, living facilities, landscape and parks, and the straight-line distance to Tiananmen Square. Finally, the data were screened according to the research purpose to remove the samples with crippled or unreliable information. Finally, 17,952 valid samples were obtained, of which the number of samples without elevator was 17,095, and the number of samples with additional elevator was 857. Table 1 summarizes the definitions of all the variables as well as the results of descriptive statistics.

3.3. Research design and method

First, we constructed a hedonic price model to explore the effect of the floor on the price of housings without elevators versus housings with additional elevators. After a series of preliminary tests, we found that compared with other forms of models, the logarithmic hedonic price model could better explain the relationship between housing prices and explanatory variables with the best model accuracy (Malpezzi, 2002). This model form has been developed and tested over a long time, proven to be reasonable and reliable (Wen et al., 2022). The first model was designed as follows:

$$\ln P = \alpha_0 + \beta_1 LF + \beta_2 HF + \sum \gamma_i X_i + \lambda_j + \delta_k + \varepsilon. \quad (1)$$

Table 1. Variable definition and statistic description

Variable	Description	Min.	Max.	Mean	S.D.
Housing price (*P*)	Total transaction price of a housing (CNY)	505,000	26,000,000	4,162,290	1,773,343
Area (*AR*)	Building area of a housing (m^2)	13.51	338.86	77.97	30.62
Age (*AG*)	Age of building (years)	2	71	23.21	9.00
Floor (*F*)	Floor level of a housing	1	7	3.12	2.43
Low floor (*LF*)	Whether the housing is located on a low floor (1 = yes; 0 = no)	0	1	0.16	0.37
High floor (*HF*)	Whether the housing is located on a high floor (1 = yes; 0 = no)	0	1	0.36	0.48
Elevator (*E*)	Whether the housing with an installed elevator (1 = yes; 0 = no)	0	1	0.05	0.21
South (*S*)	Whether the housing with a south-facing orientation (1 = yes; 0 = no)	0	1	0.70	0.46
Decoration (*D*)	Whether the housing well decorated (1 = yes; 0 = no)	0	1	0.41	0.49
Bedroom number (*BN*)	Number of bedrooms	0	6	2.12	0.71
Living room number (*LN*)	Number of living rooms	0	4	1.14	0.39
Educational facilities (*EF*)	Primary school, secondary school, and senior high school within 1 km of a housing, each one takes 1 score and total 3 scores	0	3	2.43	0.80
Living facilities (*LF*)	Shopping malls, 3A hospitals, post offices and banks within 1 km of a housing, each one takes 1 score and total 4 scores	0	4	3.41	0.73
Traffic facilities (*TF*)	Bus stops and subway stations within 1 km of a housing, each one takes 1 score and total 2 scores	0	2	1.62	0.50
Landscapes & parks (*LP*)	Landscapes and parks within 1 km of a housing, each one takes 1 score and total 2 scores	0	2	1.38	0.76
Distance to distance (*D_TAM*)	Straight–line distance from a housing to Tiananmen (m)	289.02	111,815.46	15,335.10	8,461.19

In the model, P is the price of the housing, LF is whether the housing is located on a low floor, HF is whether the housing is located on a high floor, X_i is the other control variables, where the discrete variables are in their original form, and the continuous variables were introduced into the model using logarithmic form, α_0, β_1, β_2, and γ_i are the coefficients of the characteristic variables to be estimated, λ_j is the year fixed effect, δ_k is the district fixed effect, and ε is the error term.

Unlike urban public goods with complete non-exclusivity, the impact of urban semi-public goods with partial non-exclusivity, such as elevators, and electric vehicle charging piles (Gao et al., 2022) on the price of housings is more complicated. The benefits of these urban semi-public goods can only be enjoyed by residents living within specific boundaries and thus are usually defined as dichotomous variables (Tsai, 2022). If these dichotomous variables are directly added into the OLS hedonic price model, the systematic differences between dwellings equipped with urban semi-public goods and those not equipped with urban semi-public goods are often overlooked, resulting in a selectivity bias in the sample. Consequently, a PSM model with whether or not to equip an additional elevator as the core explanatory variable was constructed to remove the effect on the model caused by endogeneity from sample self-selection (Wang & Li, 2022). To enhance the robustness of the empirical results, we chose three matching methods: K-nearest neighbor matching (KNM), radius matching (RM), and kernel matching (KM). Furthermore, we retained the maximum loss data of the samples under the three different matching methods and constructed the model based on the matched data.

$$\ln P = \alpha_0 + \beta_1 E + \sum \gamma_i X_i + \lambda_j + \delta_k + \varepsilon; \quad (2)$$

$$\ln P = \alpha_0 + \beta_1 E + \beta_2 E \times F + \sum \gamma_i X_i + \lambda_j + \delta_k + \varepsilon. \quad (3)$$

E is an additional elevator variable in the model, and the interaction term $E \times F$ for floor and additional elevator were added to examine the interaction effect of floor and additional elevator on housing prices, and the other variables are the same as in Model 1.

In addition, to examine the interaction effect of orientation and additional elevator on housing prices, the single orientation feature variable and the interaction term $E \times Single$ for single orientation and additional elevator were added to the model, and the final model form was obtained as follows:

$$\ln P = \alpha_0 + \beta_1 E + \beta_2 Single + \beta_3 E \times Single + \sum \gamma_i X_i + \lambda_j + \delta_k + \varepsilon. \quad (4)$$

Single is the single orientation variable in the model, $E \times Single$ is the interaction term between the two, and the other variables are the same as in Model 1.

Likewise, the interaction term $E \times \ln AG$ for age and additional elevator were added to the model to examine the interaction effect of age and additional elevator on housing prices, and the final model form was obtained as follows:

$$\ln P = \alpha_0 + \beta_1 E + \beta_2 \ln AG + \beta_3 E \times \ln AG + \sum \gamma_i X_i + \lambda_j + \delta_k + \varepsilon. \quad (5)$$

The ordinary least squares (OLS)-based regression method ignores the real estate market differentiation effect of the additional elevator premium. To capture the change in the additional elevator premium in the distribution of housing prices in the overall market, we introduced a quantile regression model to assess the heterogeneous impact of the additional elevator on the housing prices at different price points in the form of the following model:

$$\ln P = \alpha_0(\tau) + \sum \beta_j(\tau) E + \sum \gamma_i(\tau) X_i + \lambda_j + \delta_k + \varepsilon, \quad (6)$$

where τ is the quantile point, and the other variables are consistent with the baseline model.

4. Results and discussion

4.1. Impact of the floor level on housing prices

Table 2 presents the results of OLS regression analysis for the sample without an elevator and the sample with an additional elevator. We compared the results of the regressions for the two sets of samples and analyzed them. Based on our analysis, we conclude that for the sample without elevator, the impact coefficient of low floors on housing prices is 0.004 and non-significant, and the impact coefficient of high floors on housing prices is −0.063 and significant at the 1% level, indicating no significant differences between housing prices of middle floors and those of low floors, and that the housing prices of high floors have decreased by 6.3% compared with middle floors. This suggests that for housings that are not equipped with elevators, residents are more concerned about the positive externalities of the convenience of travel on the middle and low floors than the negative externalities due to their uncomfortable environmental factors. They show a higher willingness to pay for middle and low-floor housings compared with high-floor housings. While in the analysis of Model 2 on the sample of adding elevators, the coefficient of the impact of low floors on the price of housings is −0.055 and significant at the 5% significant level, the coefficient of the impact of high floors on the price of housings is 0.014 and non-significant, the price of housings in the middle floors and high floors is not significantly different, and the price of housings in the low floors compared with those in the middle floors decreases by 5.5%. Most additional elevator housings were built in the 20th century in older communities, where drainage and community environment are poorer, and residents living there are more likely to feel the noise, mosquitoes, humidity, and air pollution caused by low floor (Maloutas & Botton, 2023). In this case, they express a higher willingness to pay for the additional elevator high-floor housings that compensate

Table 2. Empirical results of without elevator sample and installed elevator sample

Variable	Without elevator sample		Installed elevator sample	
	Coef.	*p*-value	Coef.	*p*-value
LF	0.004	0.277	–0.055**	0.048
HF	–0.063***	0.000	0.014	0.477
ln*AR*	0.776***	0.000	0.827***	0.000
ln*AG*	–0.040***	0.000	–0.034*	0.083
S	0.032***	0.003	0.027	0.282
D	0.052***	0.000	0.064***	0.001
BN	0.034***	0.000	0.058***	0.001
LN	0.014**	0.015	0.020	0.371
EF	0.007***	0.000	0.006***	0.000
LF	0.018***	0.000	0.033***	0.007
TF	0.071***	0.000	0.055**	0.011
LP	0.023***	0.000	0.003	0.826
ln*D_TAM*	–0.159***	0.000	–0.158***	0.000
Constant	13.617***	0.000	13.714***	0.000
Year FE	Yes		Yes	
District FE	Yes		Yes	
Adj. R^2	0.820		0.713	
Observations	17095		857	

Notes: ***, **, and * indicate that the estimates are significant at the 1%, 5%, and 10% levels.

for the negative externalities of accessibility. Comparing the results of the two sets of regressions reveals a difference in the effect of the floor on the price of dwellings in the no-elevator sample and the additional-elevator sample. Therefore, H1 is partially verified.

4.2. Impact of additional elevators and floor level on housing prices

Subsequently, we applied the PSM–hedonic model to analyze the differential premium of adding an elevator to housings on different floors. After using the PSM method to deal with endogeneity due to sample self-selection, the maximum loss data of the samples under the three different matching methods were retained, and based on the matched data, the economic premium generated by the addition of elevators on different floors of housings was analyzed. Based on our results (Table 3), we conclude that the effect of adding an elevator is significant at the 1% level for the full sample as well as for the middle- and high-floor samples, while the effect on the low-floor sample is not significant. Specifically, the estimated coefficient value for adding an elevator in the full sample is 0.054, a result that suggests that the addition of an elevator housing is 5.4% more expensive than a housing without an elevator. Furthermore, residents living in housings on middle and high floors are willing to pay more to live in a housing with an elevator, and the magnitude of the effect is in the order

Table 3. Results of basic regression and interaction analysis of the effect of floor level and additional elevator on housing prices

Variable	Whole sample		LF sample		MF sample		HF sample	
	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3
E	0.054***	–0.023***	0.024	0.011	0.070***	–0.007***	0.119***	–0.061***
$E \times F$		0.025***		0.008***		0.019***		0.033***
Constant	13.533***	13.462***	13.120***	13.099***	13.608***	13.573***	13.813***	13.721***
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.814	0.814	0.794	0.794	0.818	0.818	0.824	0.825
Observations	17750		2617		8643		6124	

Notes: ***, **, and * indicate that the estimates are significant at the 1%, 5%, and 10% levels.

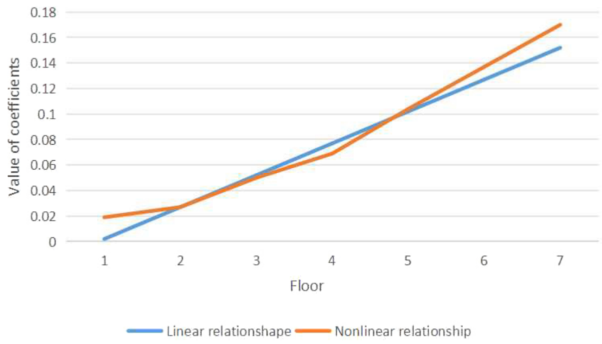

Figure 1. Relationship between additional elevator economic premium coefficients and floor level

of high floors (0.119) > middle floors (0.070). This suggests that the positive externality of convenience of travel from additional elevators gradually increases as the floor rises, and H1 is verified. However, residents living on the lower floors are unwilling to pay more for living in a housing equipped with an original elevator. This is ascribable to the fact that the additional elevator does not reduce their travel costs and even negatively affects their lives due to the impact on the ventilation and lighting of the housing.

In addition, in order to further analyse the change in the economic premium of adding elevators with the floor, we added an interaction term $E \times F$ to Model 2 and plotted Figure 1. The positive coefficient of $E \times F$ shows that as the floor increases, the coefficient of adding elevators will increase, further illustrating the floor differences in the premium of adding elevators. Besides, we further confirmed the nonlinear relationship between floor and the coefficient of adding elevators through a regression with low, medium and high floor sub-samples. Specifically, the coefficient of adding elevators does not increase uniformly with the floor level. It increases slightly at low floor level, while increases dramatically at medium and high floor level.

4.3. The moderating effect of orientation and age on the premium for additional elevators

The addition of an elevator, while convenient for residents to get around, also negatively impacts the safety, silence, lighting and ventilation in the housing. This negative impact is more pronounced for single-facing and older housings than for newer and multi-facing housings. On the other hand, the floor level is an important factor influencing the silence and lighting of a house, and the effect of adding an elevator on the silence and lighting of houses on different floors may also be different (Jia et al., 2014). To explore the impact of orientation and housing age on the premium of adding elevators for housings on different floors, we introduced the single orientation variable into the model as well as the interaction term $E \times Single$ and $E \times \ln AG$ for hedonic price analysis. The results of the analysis are summarized in Table 4. The direction and significance of the effect of single orientation on the price of dwellings is not stable in the regressions for the full sample as well as for the low-, middle- and high-floor samples. However, the coefficient on the interaction term $E \times Single$ and $E \times \ln AG$ are significantly negative in the full sample as well as in the regressions for the low-, middle- and high-floor samples. This suggests a moderating effect of orientation and housing age on the premium for adding an elevator. In contrast, the benchmark model only captures the average premium for adding an elevator. With this, H2, H3 was tested.

To compare the difference between the premium for adding an elevator to a single-facing housing and a multi-facing housing on different floors, we plotted a line graph of the premium for adding an elevator (Figure 2). The coefficients of the model's add-elevator variable are the coefficients of the premium for adding an elevator to a multi-facing housing. The coefficient on the interaction term is the coefficient on the housing price loss of adding an elevator to a single-facing housing compared with a multi-facing housing. The coefficient on the premium

Table 4. Interaction analysis of the effect of orientation, age and additional elevator on housing prices

Variable	Whole sample		LF sample		MF sample		HF sample	
	Model 4	Model 5	Model 4	Model 5	Model 4	Model 5	Model 4	Model 5
E	0.090***	0.133***	0.045**	0.040*	0.094***	0.103***	0.156***	0.217***
ln*AG*	–0.065***	–0.062***	–0.055***	–0.059***	–0.083***	–0.080***	–0.083***	–0.071***
Single	–0.000		–0.016		0.029***		–0.025***	
$E \times Single$	–0.123***		–0.091***		–0.125***		–0.151***	
$E \times \ln AG$		–0.015***		–0.005**		–0.013***		–0.039***
Constant	13.594***	13.535***	13.175***	13.140***	13.590***	13.551***	13.928***	13.782***
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.815	0.815	0.794	0.794	0.820	0.818	0.826	0.824
Observations	17750		2617		8643		6124	

Notes: ***, **, and * indicate that the estimates are significant at the 1%, 5%, and 10% levels.

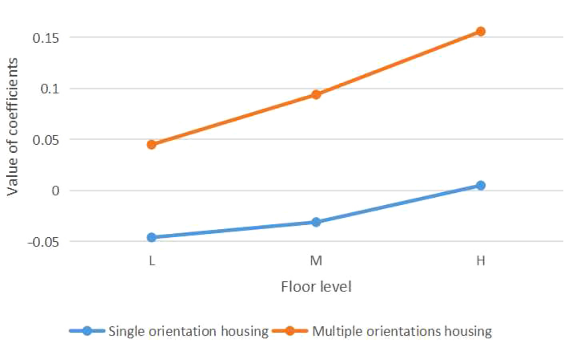

Figure 2. Additional elevator economic premium coefficients in single and multiple orientation samples

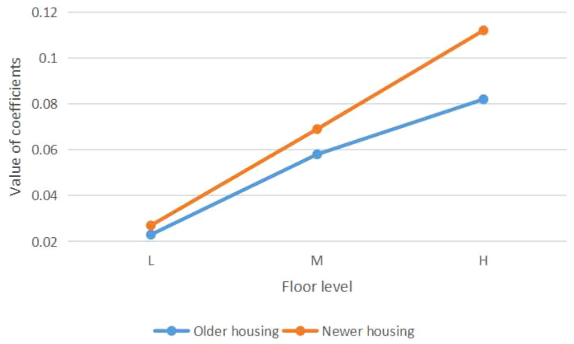

Figure 3. Additional elevator economic premium coefficients in older and newer samples

for adding an elevator to a single-facing housing is thus the sum of the coefficients on the add elevator variable and the coefficients on the interaction term in the model. For the full sample, the premium coefficient of adding an elevator for multi-directional housings is 0.090, whereas the premium coefficient of adding an elevator for single-directional housings is −0.033. That is to say, adding an elevator for single-directional housings not only does not increase the price of housings but also decreases the price of housings by 3.3%, which reflects a strong negative externality of adding an elevator for single-directional housings. Regarding floor heterogeneity, the coefficient of housing price loss for adding an elevator to a single-facing house increases as the floor rises. This is related to the fact that higher floors have better light and views. Compared with the middle and lower floors with average light and views, the shading of an additional elevator has the greatest impact on the lives of residents of the higher floors who would otherwise have a wider view. For multi-facing housings, adding an elevator will increase the price of housings on the middle and upper floors. For single-facing housings, adding elevators will only increase the price of housings on the higher floors, reducing the price of housings on the middle and lower floors. This is the result of the trade-off between the negative externality of adding elevators affecting lighting and ventilation and the positive externality of reducing travel costs.

Similarly, in order to compare the difference in the premium for adding an elevator to newer and older housings on different floors, we plot Figure 3. The negative coefficient on $E \times \ln AG$ indicates that the premium coefficient for adding an elevator decreases as the age of the housing increases. Specifically, the coefficient of premium for adding an elevator is 0.093 for newer housings (with $\ln AG$ one standard deviation below the mean) and 0.081 for older housings (with $\ln AG$ one standard deviation above the mean) in the full sample, suggesting that negative externalities such as safety hazards and noise associated with the addition of elevators have a stronger impact on older housings with a lower level of construction. In terms of floor heterogeneity, the coefficient of $E \times \ln AG$ increases with the rise of floors, which is due to in the additional elevator buildings, due to the initial design did not reserve the space for the winch, and thus the winch is often installed on the top floor, causing great noise nuisance to the residents of the upper floors. For older housings with thinner walls, the intolerable noise caused by the winch has a stronger impact on the lives of residents of the upper floors.

4.4. The socially heterogeneous impact of additional elevators on housing prices

From the quantile regression results in Table 5 and Figure 4, we deduce that the impact of the variable of additional elevator on the price of housings at different quantile points is different. We only report the coefficients of adding an elevator due to space considerations. In the first column, the impact of additional elevator on the price of housings at Q0.1 is not significant, and the semi-elasticity coefficient of additional elevator on the price of housings at Q0.9 reaches the maximum value of 0.102. Furthermore, the coefficient shows a gradual increase from the low- to the high-quantile points, which indicates that buyers of high-priced housings will pay more attention to the elevator configuration of the housing, while purchasers of low-priced housings do not pay much attention to the additional elevator, H4 was tested. As stated earlier, buyers of high-priced housings generally have higher incomes; they have higher demand for life-enhancing amenities, such as additional elevators as well as for the environment of the community in which their housings are located. The plot ratio of the high-end community is generally lower, and the negative externalities of the additional elevator affecting ventilation and lighting are limited, which tend to produce a relatively high premium for the additional elevator. For low-priced housings, the relevant facilities and the surrounding environment are poor, and the community floor area ratio is high. At this time, the addition of elevators will largely affect the ventilation and lighting, thus affecting buyers' willingness to pay. Therefore, the quantile regression results show the above trend.

Next, to analyze whether there is a difference in the premium for adding an elevator for low-, middle- and

Table 5. Results of quantile regression

Quantile	(1)	(2)	(3)	(4)	(5)	(6)
	Whole sample	LF sample	MF sample	HF sample	AH sample	CH sample
OLS	0.054***	0.024	0.070***	0.119***	0.052***	0.047***
Q.0.1	–0.010	–0.099***	–0.009	0.064***	0.019***	–0.015
Q.0.2	0.031***	–0.027*	0.014	0.083***	0.050***	0.027***
Q.0.3	0.038***	–0.009	0.024**	0.091***	0.054***	0.032***
Q.0.4	0.053***	–0.003	0.031***	0.125***	0.058***	0.056***
Q.0.5	0.087***	0.013	0.058***	0.148***	0.059***	0.080***
Q.0.6	0.091***	0.016	0.087***	0.155***	0.080***	0.095***
Q.0.7	0.098***	0.042	0.090***	0.156***	0.082***	0.099***
Q.0.8	0.102***	0.050*	0.091***	0.158***	0.073***	0.103***
Q.0.9	0.102***	0.055***	0.093***	0.159***	0.062***	0.108***
Observations	17750	2617	8643	6124	5996	11754

Notes: ***, **, and * indicate that the estimates are significant at the 1%, 5%.

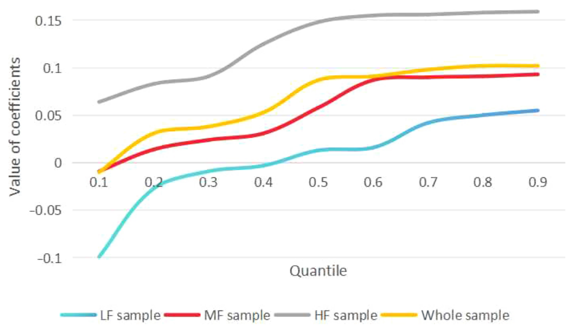

Figure 4. Quantile regression results of the whole sample and floor-level sub-samples

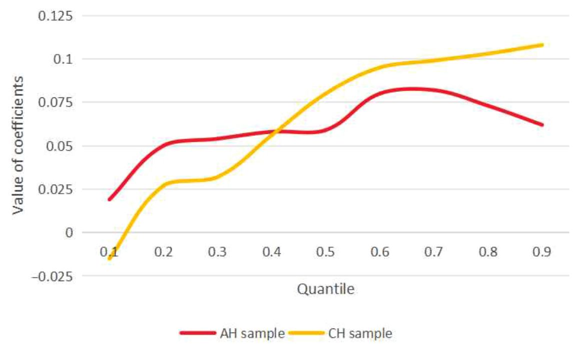

Figure 5. Quantile regression results of commercial housing and affordable housing samples

high-floor housings at different quartiles, we re-established the quartile regression model based on the market segments of low, middle, and high floors. For low-floor housings, the premium coefficient of adding an elevator is significantly negative between Q0.1 and Q0.2, significantly positive between Q0.8 and Q0.9, and non-significant between Q0.3 and Q0.7, suggesting that adding an elevator reduces the price of low-priced housings on low floors and raises the price of high-priced housings on low floors. This is attributable to the weaker positive externality of the additional elevator on low floors to facilitate travel. As the price of the housing rises, the grade of the community improves, and the floor area ratio increases, the negative externality of the additional elevator on low floors that affects the ventilation and lighting is weakened, its net externality shifts from negative to positive, and the premium coefficient also gradually increases. As for the middle- and high-floor housings, except for the premium coefficient of adding elevators on middle floors, which is not significant at Q0.1 and Q0.2, all other coefficients are significant, and the coefficients exhibit a trend of gradual increase. The elevator premium increases with the rise of the price of housings, similar to the results of the whole sample regression.

Column (5) and (6) encapsulates the estimation results based on OLS regression and quantile regression using the sample data of commercial and protected housing, which show that the coefficients of additional elevator premiums for commercial and protected housing are 0.047 and 0.052, respectively, and both of them are significant at the 1% level. That is to say, under other conditions, the prices of commercial housing and affordable housing with elevators are respectively 4.7% and 5.2% higher than that of housing without elevators, and the premium for affordable housing with elevators is slightly higher than that of commercial housing. The strong demand for additional elevators from mobility-impaired residents in the affordable housing community outweighs the depreciation of the investment value of additional elevators due to poor liquidity in the affordable housing market. Figure 5 show the changes in the coefficients of the premiums for adding elevators at different quartiles, H5 was tested. The results demonstrate that the premium coefficients of adding elevators for commercial housing housings show a gradual increase from the lower to the higher quartile points, which is not significantly different from the results of the previous analysis for the full sample. However, for affordable housing, the premium coefficient of adding elevators shows a trend of increasing and then decreasing from the low to the high tertile, which can be analyzed from the two aspects of the use value and investment value of residential housing. For low- and middle-priced housings, buyers are more concerned about the use value of housings, and the strong demand for additional elevators from mobility-impaired residents in the affordable housing community triggers a higher willingness to pay. For middle- and high-priced housings, buyers are more concerned about the investment value of housings, and the poor liquidity in the housing market leads to the loss of the investment value of the additional elevator, which has never been noticed by scholars before (Ma et al., 2018).

5. Conclusions and policy implications

With the gradual aging of the population, age-friendly multistory houses equipped with elevators are increasingly favored by home-buyers. In this study, we used the PSM–hedonic and quantile–hedonic models to delve into people's willingness to pay for an additional elevator. In contrast to existing studies, while analysing the change in the premium for additional elevators with the floor, we also discussed in depth the possible negative impact of additional elevators on residents' lives through the moderating effect of orientation and age of the housing (Liu & Sun, 2019). Additionally, we comprehensively examined the differences in the premiums for adding an elevator in two housing markets, commercial community housings and affordable community housings, which has never appeared in previous studies (Ning, 2014).

The above findings reveal an important reference for promoting the project of adding elevators to existing housings in old neighborhoods. First, in carrying out renovation projects to add elevators to old residential areas, when faced with the demands and conflicts of owners on different floors regarding damage and benefits, compensation and contributions, etc., grassroots staff such as street offices and neighborhood committees can refer to the quantitative results in this article, use quantitative data as the basis for communication work, and alleviate communication conflicts. This provides a basis for appropriately charging and subsidising residents on different floors. Second, when setting up a funding model for elevator retrofitting, the differences in price due to floor level, orientation, age, housing price and community type should be taken into account to determine a reasonable model for additional elevator installation. Specifically, for single-oriented buildings and buildings that are too old, the relevant departments need to carefully assess the lighting, sound insulation and safety of the building before adding an elevator to avoid negative impacts. For low-value communities and affordable housing communities, the relevant departments should do a good job of subsidising and publicising the work to ensure that the benefits of adding elevators are enjoyed by residents in need as much as possible. Finally, the measurement of the benefits of retrofitting elevators in old communities and the construction of a funding mechanism provide a reference for the implementation of other improvement and upgrading urban renewal projects. For other types of urban renewal projects, local authorities can also first measure their economic benefits, guide the beneficiaries of the project to make reasonable contributions, solve the financing difficulties of urban renewal projects, alleviate the financial pressure on local governments, and promote the stable and long-term development of urban renewal.

However, our study still has some limitations. First, as the same housing is not usually traded repeatedly for a short period of time, we could not get the transaction prices before and after the addition of lifts to the same housing, and we did not use methods such as DID to explore the changes in the price of housings before and after the addition of elevators, which is an important direction for our future research. Second, due to the limitation of technical means, we could inaccurately obtain the lighting time of each housing and only used the orientation variable to explore the negative externality of adding elevators, which concluded that the study was not precise and comprehensive enough. Therefore, using urban 3D modeling and other means to fully understand the impact of additional elevators on residential lighting is a research topic worthy of attention by future scholars. Finally, due to privacy protection reasons, we do not have access to personal data of home-buyers. If data on the personal characteristics or demand of home-buyers is available, it may be possible to further enrich understanding of the impact of additional elevators on housing prices from the perspective of demand differences.

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Author contributions

Zhao Zhang was responsible for formal analysis, writing original draft and writing review & editing. Yihua Mao was responsible for conceptualization, methodology and funding acquisition. Yueyao Shui was responsible for investigation. Ruyu Deng was responsible for data curation.

Disclosure statement

The authors declare that they do not have any competing financial, professional, or personal interests from other parties.

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Appendix

To ensure the reliability of the PSM results, we conducted the overlap test for the model. As depicted in Figure A1, a significant difference exists in the kernel density distribution between the total sample treatment group and the control group before matching. The trend of kernel density curves of the two groups of samples tends to converge after matching, and the propensity scores have a large range of overlap, with most of the observations within the common range of values. From this, we conclude that the matching effect is ideal and satisfies the common support hypothesis. The same holds true for the common support test for the low-, middle-, and high-floor subgroups, which will not be repeated here for space reasons.

In addition, we tested the balance of covariates, after matching, whether there are significant systematic differences in covariates between the control and treatment group housings, apart from the differences in prices. From the results of the balance test (Table A1), it is evident that the standardized total bias of the explanatory variables is significantly reduced after sample matching. The Adj. R^2 decreases from 0.338 before matching to 0.015–0.020 after matching, and the LR statistic decreases from 2,325.84 before matching to 36.39–47.99. Based on the analysis of the above test results, it can be seen that applying the PSM method effectively reduces the number of covariates and differences in the distribution of explanatory variables between the control group and the treatment group and eliminates the estimation bias caused by sample self-selection.

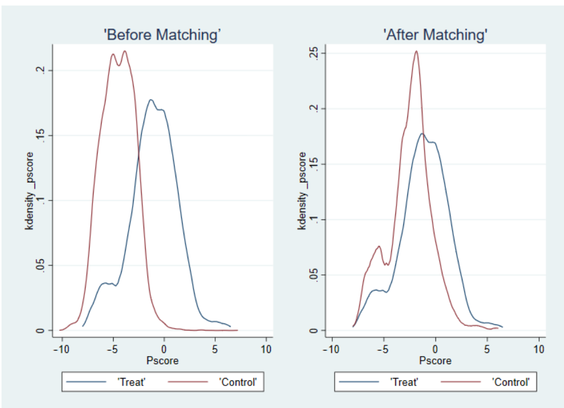

Figure A1. Kernel density function plot before and after matching

Table A1. Results of balance test

Sample	Match method	Adj. R^2	LR statistic	Standardized total bias
Whole sample	prematch	0.338	2325.84	0.90
	KNM	0.020	47.99	0.50
	RM	0.015	36.39	0.20
	KM	0.020	47.99	0.50
Low floor sample	prematch	0.379	372.88	0.56
	KNM	0.081	26.55	0.22
	RM	0.038	11.58	0.11
	KM	0.051	15.69	0.11
Middle floor sample	prematch	0.330	1073.30	0.89
	KNM	0.009	9.77	0.11
	RM	0.011	11.60	0.11
	KM	0.019	20.69	0.11
High floor sample	prematch	0.350	926.63	1.00
	KNM	0.032	29.69	0.22
	RM	0.029	26.65	0.22
	KM	0.041	38.48	0.22