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Premium Effect and Compensation Mechanism for Installing Elevators in Old Residential Buildings in China

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Abstract

The installation of elevators in old residential buildings in China has become a pressing issue, with significant implications for property values, resident well-being, and social equity. We provide empirical research on the effects of cost sharing, compensation, and residential building price premiums after elevators are installed in old residential buildings in China. Utilizing data on 2,133 resale properties in Shanghai's Hongkou District from February 25 to March 3, 2020, we find that when the government subsidizes households more than it does elevator service providers, the decision-making strategies of households and elevator service providers are consistent, and the price of the residential building increases significantly after the elevator is installed. Furthermore, our results indicate the third floor is the critical floor for cost-benefit conversion after incorporating various factors that determine premium pricing for different floors into the subsidy policy. Consequently, the households on floors below the third floor should be adequately compensated because they are impacted the least in terms of the convenience and price premiums of installing elevators, and households on floors from the third floor up should share the cost of installation. Grounded in evolutionary game theory, this study highlights the necessity of considering the spatial heterogeneity of quasi-public goods and formulating a scientific and effective compensation mechanism when installing elevators in aging buildings.

Keywords: Installing Elevators, Quasi-public Goods, Premium Effect, Spatial Heterogeneity, Compensation Mechanism, Residential Buildings

1. Introduction

There is a famous story about installing elevators in China by Peter Hessler, a staff writer for *The New Yorker.* In his column titled "China's Reform Generation Adapts to Life in the Middle Class," Hessler, a former China correspondent for the magazine, writes about elevators being added to existing multistory residential buildings in China during the millennium, and entrepreneur North, whose company was responsible for such installations, after determining the cost structure through negotiations with residents, including between those on the lower and upper floors [1].

This is a very common scenario in China's urbanization process. According to the 2020 edition of Shanghai Engineering Construction Regulations Residential Design Standards, multistory residences refer to buildings with four to six floors for family living. Existing multistory residential buildings mainly refer to the urban collective residential buildings that were built between 1970 and 1990. Limited by the cognition, technical, and economic conditions at the time, there were no elevator facilities during the construction of such residential buildings, including some high-rise buildings such as the 12-story building in Fuling, Chongqing that the article refers to. After 2000, the situation improved, but only a little as the government stipulated only residential buildings with more than seven floors were to be equipped with elevators. According to the calculations of the Ministry of Housing and Construction, about eight billion sq. meters of residential buildings were built in China from 1980 to 2000. However, more than 70% of the existing multistory residential buildings for older adults in urban areas were not equipped with elevators.

The installation of elevators in existing residences not only improves the quality of life of the households on the upper floors, but also eases the difficulty of providing care for older adults at home. In addition, the value of certain floors in such buildings increased after elevators were installed. However, it was difficult for households on different floors to agree to add elevators because of the differences in premiums. The government introduced several policies, such as restricting the voting rights of households on the first floor by changing the one-vote veto system to two-thirds approval; however, progress has been slow. As of May 2019, the total number of elevators installed nationwide was approximately 30,000 units, far fewer than the actual demand of 2.5 million units. In addition, Beijing successfully installed the first elevator seven years after the policy was introduced.

Scholars have discussed the evolution of this policy from multiple perspectives, including politics and management. A few have considered economic theories and tools to determine adequate compensation after the installation. However, few studies quantified the change in capitalization due to adding elevators to old buildings, or incorporated this concept into the design of cost-sharing and compensation mechanisms.

Based on the perspective of quasi-public-goods theory, this study selects a six-story residential building in a community in Hongkou District, Shanghai as a sample. It considers whether the building is equipped with an elevator as the core explanatory variable. Data on 2133 housing market transactions for older buildings are obtained from the Chinese real estate company Lianjia's official website for the period February 25 to Marth 3, 2020 using Python. The impact of the installation of elevators on the unit price of apartments on every floor is assessed to calculate the compensation benefits and cost-sharing of elevator installations, which has practical significance for the installation of elevators in old residential buildings in China.

2. Literature Review

2.1 Installing Elevators and Game Theory

The installation of elevators in existing residential buildings is a type of quasi-public-goods supply in the local neighborhood. Public goods were first defined by the Swedish economist Lindahl in Fair Taxation [2]. Samuelson divided goods into private and public [3]. Public goods have the characteristics of non-competitive and non-exclusive consumption; a person consuming purely public goods or services does not reduce other people's consumption of such goods or services. Buchanan proposed the concept of club goods, which cover all cases from purely private to public goods [5]. Ostrom divided goods into purely public goods, public pond resources, club products and private goods according to their exclusiveness and competitiveness. Public pond resources refer to those goods that are competitive but not exclusive, such as parks, public swimming pools, and pastures [5]. Club products refer to exclusive but non-competitive goods, such as fee-paying clubs, and expressways. Fan, He, and Zhou and Tang point out that urban community public goods are characterized by incomplete exclusivity and competition whereby consumption is limited to community households, and when the number of consumers exceeds a certain limit, there is congestion [6-8]. Barzel refers to these goods as quasi-public goods [9]. Therefore, community elevators can be defined as quasi-public goods with low levels of public consumption, which are similar to private goods.

Essentially, elevators are added to existing multistory residences to solve the supply problem of public goods in urban communities, provided the stakeholders collectively decide on them. Yang states that the installation of elevators in existing multistory residences involves six stakeholders: households, government, community-based organizations, community non-profit organizations, elevator companies, and property service companies [10]. In participating in the supply of public goods in urban communities, the suppliers' own interests and goals may lead to opportunistic behaviors because of objective factors such as lack of corresponding information management and control, and information asymmetry [11]. Therefore, it is essential to analyze the installation of elevators in urban communities from the perspective of game theory. The specific performance of the game behavior is as follows. First, there is a game between households, property service companies, and government. He et al. find that households, property service companies, and the government have different requirements [12]. However, because of information asymmetry between households and property service companies, imperfect laws and regulations, and a lack of government supervision and guidance, the three parties will play dynamic competition games.

The second is the static game of multiple people as households. Qu finds that there are interpersonal differences in the community's demand for installing elevators, which lead to a game between upper- and lower-floor households [13]. For example, households on the upper floors may benefit from free rider behavior due to the different levels of demand and the non-exclusive use of elevators. Wu and Chen further subdivide the households into lower-, middle-, and upper-level households [14]. The agreement must be supported by all three, or at least two parties must agree to install the elevators. Zhou and Tang discuss the not-in-my-backyard effect of adding elevators [8]. Households on the first floor generally do not expressly demand financial compensation because of their relationships with other households. However, they express their choices implicitly by opposing the installation of elevators for reasons such as lighting, ventilation, privacy, and noise.

In classical game theory, individuals often maximize their own interests and therefore do not adopt cooperative strategies. In addition, individual rational behavior leads to collective irrational results. Evolutionary game theory incorporates the irrational and bounded rational behaviors of individuals and the population's thought processes, which creates a reasonable mechanism within which cooperation is possible [15]. The game of installing elevators in a community faces the same scenario. Tang and other scholars propose that when low-rise households receive a certain amount of compensation, the Nash equilibrium can be reached [16]. If a cost-sharing model is used, the costs can be distributed among households on different floors, differently, to avoid free rider behavior [17-19].

2.2 Cost-Sharing Mechanism for Installing Elevators

The problem of installing elevators in existing multistory residences is complex. Even if all households agree to install elevators, it is still difficult to coordinate specific elevator cost allocations and compensation. Many scholars have proposed different ideas and countermeasures to solve this challenge. To estimate the factors for the cost of installing elevators, Bai et al. introduced the perspective of project lifecycle costs to compensate for the cost of installing elevators being limited to engineering costs, and include the maintenance and operating costs of the elevators after installation into the cost estimation model [17]. Ning suggests that the shared and compensation costs for each floor should be determined according to the frequency of elevator usage, the building's price appreciation rate, and the willingness to install [19].

In terms of sharing the installation costs of elevators, Li and Xu, consider that the households on the first floor do not need to share in the costs, and establishes a distribution which includes calculating the income of the virtual cooperation function to determine the cost sharing ratio [18].

Bai et al [17]. and Ning recommend fixing a critical floor as the cut-off point for apportionment or compensation, meaning that compensation is paid to the households below the critical floor, and households on or above the floor are charged for installation [19]. Wang and Song introduce the theory of disagreement management, decomposing the cost of installing elevators according to their function and purpose, and propose that only the common parts such as the elevator shaft and electromechanical equipment, be negotiated and shared [20]. Liu and Sun establish a cost-sharing and loss compensation model based on the voting game, which calculates the cost-sharing and compensation ratio for the elevator installation [21]. Zhang constructs a cost allocation model based on the increase in the housing-use value and calculates the allocation coefficient of each floor by using the weighted average of the use-value increment coefficient for each floor, and the floor-price-difference coefficient [22]. Xiang and Huang analyze the special form of installing elevators in old residential buildings from the perspective of community public affairs and introduce boosting theory, which considers both economic and non-economic factors to solve the problem of elevator installations in these residences [23].

2.3 Capitalization Effect of Adding Elevators

The capitalization effect on urban public goods is relatively extensive. Scholars have studied the capitalization of urban public goods in terms of housing prices from different perspectives such as transportation convenience, education quality, distance from parks, public security level, space quality, and green space environment, all of which result in a premium effect. Kovacs, for example, considers two regional parks in Oregon and finds that the value of a home is maximized when it is located a certain distance from the park [24]. Ren and Li use a geographical weighted regression model to analyze the capitalization effect of Chongqing parks on residential prices and find that it has obvious spatial differentiation characteristics [25]. Through empirical analysis, Huang and Shi find that urban public goods such as subways, parks, green spaces, and primary schools are reflected to a significant degree in the surrounding house prices [26].

As a quasi-public good, there is also a capitalization effect of the installation of elevators in existing residences, which is reflected in the changes in the rental and transfer prices of apartments on each floor. Zhang uses the potential rental income of residential building to quantify the improvement in its use value after an elevator is installed [22]. In addition, the author measures the change in the transfer value of the residential building by changing the order of floor prices and the ratio of residential building price appreciations.

To summarize, the recent works on elevator installations in urban communities and their valuable findings provide a theoretical basis for this study. However, few studies have quantified the capitalization effect of adding elevators in urban communities and incorporated that into the design of cost–sharing and compensation mechanisms.

3. Design and Analysis of An Evolutionary Game Model for Installing Elevators

The existence of externalities in an elevator installation project for multistory residential buildings causes the market allocation mechanism to fail. Therefore, the promotion of the project requires the government to intervene and manage the project to encourage the efforts of the households and elevator service providers. Based on market equilibrium, the optimal allocation of social resources can be achieved by realizing the gradual increase in the number of existing residential installations.

3.1 Model Assumptions

This study assumes that three parties are involved in the installation of elevators in multistory residential buildings: households, elevator service providers, and government departments. The following conditions are assumed for Scenario 1.

1. The households and elevator service providers have the same goals. Under the constraints of a government incentive contract, if the households are willing to install an elevator in the building, they will actively sign a contract with the service provider and request for installation.

2. Both the households and elevator service providers are bounded rational. In the initial stage of the game, they are driven by the motive of maximizing their own interests. Simultaneously, the households and service providers are highly intelligent with high cognitive and learning abilities and can continuously adjust their strategies in the middle and late stages of the game.

2. In the game process, the principle of fairness is affected when the government intervenes. Therefore, the benefit-sharing coefficient is set to represent government consideration of the interests of households and elevator service providers.

3.2 Parametric Design

Because government departments can choose to intervene or not in the installation of elevators, and households and service providers can also choose to participate or not, this study assesses the situation using different behavioral models and scenarios to determine the benefits for every participant.

Scenario 1: The government does not offer any incentive or interference in the elevator installation project. Furthermore, neither the households nor the elevator service provider participate in the elevator installation project. In this scenario, the external benefit is F_g, the resident's benefit is R_o, and the elevator service provider's benefit is S_e.

Scenario 2: The government offers an incentive. Therefore, the net externality benefit of the government is $F_g + Z_g - C_t - C_g$, that of the households is $R_o + Z_o + P_o - C_o$, and that of the elevator service provider is $S_e + Z_e + P_e - C_e$. In this scenario, Z_g, Z_o, and Z_e are the gains of the government, households, and service providers, respectively, after the implementation of the elevator renovation project. Z_g reflects the external effects of the renovation of old residential buildings on creating harmonious community relationships and promoting social employment; Z_o measures the convenience to the households from the elevator installation and the gain in residential building prices; and Z_e measures the increase in the service providers' business income from the installation. C_t and C_g represent the cost paid by the government to encourage the installation of elevators in old residential buildings, where C_t is the cost of promotion, publicity, and management in the early stages and C_g is the direct financial subsidy. C_o and C_e represent the cost that households and elevator service providers must pay to install the elevators, P_o is the subsidy provided to the owner, and P_e is the subsidy provided to the service provider. The government's financial subsidy incentives are distributed between households and service providers according to a certain income-sharing coefficient α and satisfy:

$$P_o = (1-\alpha)C_g;\ P_e = \alpha C_g, \text{ so that } P_o + P_e = C_g.$$

Scenario 3: The government does not provide any incentive. However, as the households and elevator service providers decide to initiate the elevator installation and renovation, it is assumed that the government can still obtain external benefits H_g at this time from the behavior of households and service providers. However, they can only maximize their own benefits and not the overall social benefits; therefore, $H_g < Z_g$.

Scenario 4: The government offers financial incentives to the elevator installation project but the households and elevator service providers do not participate in the renovation. Therefore, the government only loses the previous publicity and management services C_t related to the financial subsidies. The subsidies are usually paid after the project is completed; therefore, C_g does not reflect a loss if the project is not finally implemented.

During the entire process of installing elevators in old residential buildings, the government chooses two strategies: incentive and no incentive. The possibility of offering an incentive is Y, and of not offering an incentive is 1-Y. The specific behavior decision-making matrix of each participant is shown in Table 1.

Subjects of contract		**Governments** Incentive（Y）	**Governments** No incentive $1-Y$
Households	Participates	$(R_o + Z_o + P_o - C_o, F_g + Z_g - C_t - C_g)$	$(R_o + Z_o - C_o, F_g + H_g)$
	Does not Participate	$(R_o, F_g - C_t)$	(R_o, F_g)
Elevator service providers	Participates	$(S_e + Z_e + P_e - C_e, F_g + Z_g - C_t - C_g)$	$(S_e + Z_e - C_e, F_g + H_g)$
	Does not Participate	$(S_e,\ F_g - C_t)$	$(S_e,\ F_g)$

Table 1: Game Payment Matrix Between the Government, Households, and Elevator Service Providers

3.3 Game Strategy Choice of Households

For the households participating in installing the elevators, the proportions of those who participate and those who do not are X and 1-X respectively, assuming that the corresponding expected return utility values are $E(U_o^c)$ and $E(U_o^c)$, and the average value of the expected effect of all the owner groups is $E(U_o)$. The specific expression is as follows.

$$E(U_o^c) = Y(R_o + Z_o + P_o - C_o) + (1 - Y)(R_o + Z_o - C_o);$$

$$E(U_o^u) = YR_o + (1 - Y) R_o \tag{1}$$

$$E(U_o) = XE(U_o^c) + (1 - X)E(U_o^u)$$

$$= X(YP_o + Z_o - C_o) + R_o \tag{2}$$

The replication dynamic equation of the strategy selection mode of the owner group is further constructed as follows.

$$F(X) = \frac{dx}{dt} = X[E(U_o^c) - E(U_o)]$$

$$= X(1 - X)(YP_o + Z_o - C_o) \tag{3}$$

For the households, the first scenario is that the cost C_o of participating in the elevator installation is less than the incremental benefit Z_o. Therefore, $Z_o - C_o > 0$, which means that $YP_o + Z_o - C_o$ is always greater than zero. The replication dynamic equation equals zero, that is, $F(X) = dx/dt = 0$, and $X(1 - X)$. The equation is solved to obtain two steady-state equilibrium points $X_1^* = 0$ and $X_2^* = 1$. To further clarify the changing trend of the F(X) equation curve, F(X) is derived as: $F'(X) = (1 - 2X)(YP_o + Z_o - C_o)$.

Therefore, at the two equilibrium points $X_1^* = 0$ and $X_2^* = 1$, $F'(0) > 0$, $F'(1) < 0$. $X_2^* = 1$ is the stability of the household's optimal strategy in the evolutionary game. Accordingly, when $Z_o - C_o > 0$, that is, when the increase in convenience and residential building price rise from installing elevators exceed the cost to the households, they will choose to participate in the strategy of installing elevators in their residential buildings.

Another scenario is where the cost C_o of elevator installation is significantly greater than the comprehensive incremental benefit Z_o, that is, $Z_o - C_o < 0$. Assuming $YP_o + Z_o - C_o = 0$, then $Y = (C_o - Z_o) / P_o$, and accordingly, any value of X is the steady-state equilibrium point. However, when $YP_o + Z_o - C_o \neq 0$, the steady-state equilibrium point equals the same scenario as in the previous paragraph. It may be a steady-state equilibrium at $X_1^* = 0$ and $X_2^* = 1$, but the specific situation depends on $YP_o + Z_o - C_o$. The value difference analysis is as follows.

First, if $YP_o + Z_o - C_o > 0$, and $F'(0) > 0$, $F'(1) < 0$, then $X_2^* = 1$; this is the stable strategy of the evolutionary game, which means that the government takes incentive measures, $Y > (C_o - Z_o) / P_o$. Therefore, it effectively incentivizes households' choices to participate in the elevator installation project. Obviously, the larger the P_o, the higher the households' share of the income, and the more incentivized they are to participate.

Second, if $YP_o + Z_o - C_o < 0$, then $Y < (C_o - Z_o) / P_o$. Accordingly, F^' (0)<0, F^' (1)>0, which means that the stable equilibrium point of the evolutionary game becomes $X_1^* = 0$, indicating that if the government's incentive measures are lower than a certain threshold, it will not adequately incentivize the entire renovation project. Furthermore, the smaller the P_o, the smaller the incentive effect, and the less likely are the households to choose to participate in the installation.

3.4 Government's Choice of Game Strategy

The government's choice to incentivize or not is in accordance with the probability of Y and 1-Y, respectively, and the corresponding benefits are determined by $E(U_g^c)$ and $E(U_g^u)$, for incentives and no incentives, respectively. The average expected value of the revenue utility is $E(U_g)$, expressed as follows.

$$E(U_g^c) = X(F_g + Z_g - C_t - C_g) + (1 - X)(F_g - C_t)$$

$$E(U_g^u) = X(F_g + H_g) + (1 - X)F_g$$

$$E(U_g) = YE(U_g^c) + (1 - Y)E(U_g^u) = XYZ_g - XYH_g - XYC_g - YC_t + XH_g + F_g \tag{5}$$

The replication dynamic equation for the probability of the government's choice of strategy is:

$$F(Y) = \frac{dy}{dt} = Y[E(U_g^c) - E(U_g^u)] = Y(1 - Y)[X(Z_g - H_g - C_g) - C_t] \tag{6}$$

Assuming F(Y)=0, $X(Z_g - H_g - C_g) - C_t = 0$, that is, when $X = C_t / (Z_g - H_g - C_g)$, any value of the probability Y of the government's choice of incentive is a steady-state equilibrium point. However, if $X(Z_g - H_g - C_g) - C_t \neq 0$, two scenarios apply.

First, if $X(Z_g - H_g - C_g) - C_t > 0$, that is, $X > \frac{C_t}{(Z_g - H_g - C_g)}$, the scenarios are where $F'(0) > 0$ and $F'(1) < 0$, and the steady-state equilibrium point is Y^*=1, which indicates that the possibility of the government deciding to incentivize the installation and requiring households and service providers to participate, is not less than $C_t / (Z_g - H_g - C_g)$, which is the precondition for intervention. In the case of $X < C_t / (Z_g - H_g - C_g)$, $F'(0) < 0$, F'

(1) > 0, and $Y^*=0$ are the steady-state points.

Accordingly, the government will not incentivize installing elevators in old buildings.
However, when $X \leq 1$, and $C_t / (Z_g - H_g - C_g) > 1$, then $X < C_t / (Z_g - H_g - C_g)$ the inequality holds. If $C_t / (Z_g - H_g - C_g)$ is greater than one, then the cost of publicity and management C_t is higher than $(Z_g - H_g - C_g)$. Therefore, the government does not create an incentive.

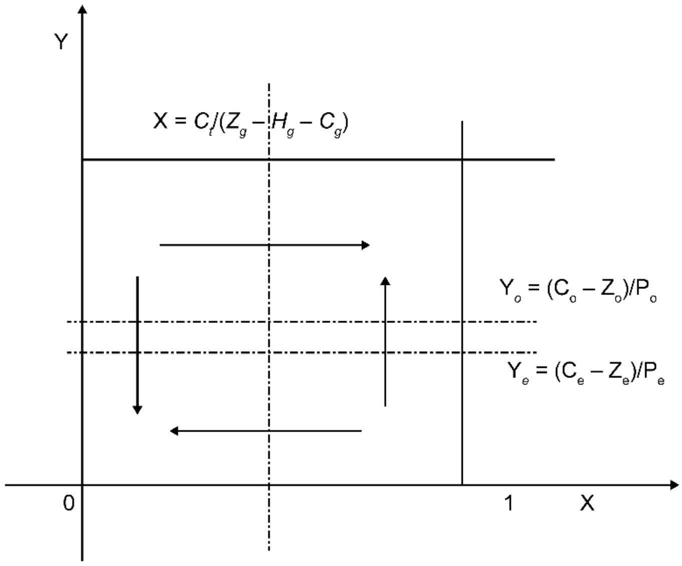

Figure 1: Evolutionary Trend of The Equilibrium Game

The stability trend diagram of the game model in Figure 1 shows that in the game of installing elevators in old residential buildings, the stable evolutionary game strategy points are (0, 0) and (1, 1). The steady state point at which the strategy converges depends on the initial game conditions: $X = C_t / (Z_g - H_g - C_g)$, $Y_o = (C_o - Z_o) / P_o$ or $Y_e = (C_e - Z_e) / P_e$. Based on the baseline for the initial evolution, the strategy combination space can be divided into four quadrants. When the values of X and Y are less than the initial baseline values, the equilibrium strategy gradually converges to the 0, 0 steady state point (in the lower left corner). In this scenario, the decision-making combination is that the households or service providers choose not to install an elevator and the government chooses not to provide an incentive. When the values of X and Y are greater than the baseline's values, the equilibrium strategy gradually converges (to the upper right) until it converges to the 1, 1 steady-state point. Accordingly, the households and service providers actively participate in the elevator installation project, and the government also provide incentives.

The government's incentive distributions to households and elevator service providers are often inconsistent. In this scenario $Y_o \neq Y_e$, which results in a difference between the households and elevator service providers. The differentiation in the stabilization strategy will inevitably lead to the failure of the elevator installation project. Therefore, to incentivize the entire elevator installation project, it is necessary to coordinate the households and service provider's choices to the extent that $Y_o = Y_e$, so that

$$\frac{C_o - Z_o}{P_o} = \frac{C_e - Z_e}{P_e} \tag{7}$$

If $P_o = (1 - \alpha)\, C_g$ and $P_e = \alpha C_g$ is substituted in Equation (7), then the value of the profit-sharing coefficient α is solved as follows.

$$\alpha = \frac{C_e - Z_e}{C_e - Z_e + C_o - Z_o} \tag{8}$$

This shows that the government should equalize the distribution of incentives between households and service providers in elevator installation projects, because an unreasonable distribution or a lack of fairness results in households and service providers making different choices, which does not contribute to synergy.

3.5 Empirical Case Analysis

The city of Shanghai has one of the highest rates of aging in China. According to statistics released by the Shanghai Municipal Office on Aging and the Shanghai Municipal Bureau of Statistics, at the end of 2020, the number of older adults aged 60 years and older with household registrations in Shanghai reached 5.8155 million, accounting for 23.4% of the total population. Many older adults, especially those in central urban areas, live in old multistory residential buildings built in the 20th century without elevators. This study selects a six-story residential building in the Hongkou District, Shanghai as the data sample for the policy analysis. Four households reside on every floor. The service life of an elevator is usually 15 years. The total cost of installing an elevator is 600,000 yuan, and the lifetime operation and maintenance costs are 200,000 yuan. The costs and benefits during the contract period to the households and the elevator service provider are listed in Table 2. According to the relevant policies of Shanghai, the government subsidies meet 40% of the total price of the elevator installation project, subject to a maximum of 240,000 yuan. Therefore, this study assumes a value of 240,000 yuan. The specific estimated government incentive costs and the various benefits and expenses of households and elevator service providers for the duration of the contract are shown in Table 2.

In this scenario, the revenue sharing coefficient is calculated as:

$$\alpha = \frac{C_e - Z_e}{C_e - Z_e + C_o - Z_o} = \frac{80 - 64.03}{80 - 64.03 + 76 - 0} = 0.174$$

$$P_o = (1 - 0.174) \times 24 = 19.824$$

$$P_e = 0.174 \times 24 = 4.176$$

These results show that the government's financial subsidies are allocated according to the calculated sharing coefficient, of which 198,240 yuan is for households to offset the cost of the elevator installation project, and the remaining 41,760 yuan is for subsidizing the service provider's later operation and maintenance costs.

Participants	**Expense type**				
	Benefit			Cost	
Governments	F_g	Z_g	H_g	C_g	C_t
	0	87.1	0	24	15
Households	R_o	Z_o	P_o	C_o	
	0	0	19.8	76	
Elevator service providers	S_e	Z_e	P_e	C_e	
	0	64.03	4.18	80	

Table 2: Government Incentive Costs and The Various Benefits and Expenses Of Households And Elevator Service Providers

4. Premium Effect and Cost Sharing Mechanism Design of Installing An Elevator

4.1 Data Acquisition and Model Setting

This study uses Stata quantitative analysis software to empirically test the fluctuation of the unit price of multistory residential buildings with elevators installed to verify whether the installation of elevators have a premium effect on the residential building price. Data on 2136 listings in the Hongkou District, Shanghai, published on the official website of Lianjia, were obtained. After eliminating entries with invalid and missing data, 2133 valid data entries were obtained. As various factors affect apartment prices, based on the available data, this study considers whether the existence of the elevator can be the core explanatory variable. In addition, the following factors are considered to assess property value: proximity to a subway, layout of the residential building (number of rooms/number of living rooms), building area, the facade (unfinished apartment, unfurnished apartment or fine decoration), number of floors, total floor area of the building, building type (tower building with shared elevators or apartment building/tower), proportion of elevators to households (number of households per floor/ number of elevators), property rights period (whether annual property rights are for 70 years or not), residential building service life (whether it is five years or not), and residential building use (whether it is an ordinary residence). Because all variables, except for the area that the building is located in, residential building type, proportion of elevator households, and total floor area of the building, are all binary or multi-value discontinuous variables, dummy variables are used and assigned values, as shown in Table 3.

Variables	Coding description
Close to subway	Not close=0, Close=1
Facade	Roughcast=0, Simple=1, Hardcover=2
Elevator equipment	Without Elevator=0, With elevator=1
Floor location	Lower floors=0, Middle floors=1, Upper floors=2
Building type	Tower building=0, Slab building=1
Term of property rights	Less than 70 years=0, 70 years=1
Residential building service life	Within 5 years=0; Over 5 years=1
Residential building use	Commercial=0, Residential=1

Table 3: Assignment of Dummy Variables for The Influencing Factors of Building Prices

The model setting is as follows.

$$\text{Residential building price} = \beta_0 + \beta_1\text{Equipped with elevator} + \beta_2\text{Close to subway} + \beta_3\text{Residential building layout} + \beta_4\text{Residential building area} + \beta_5\text{Renovation condition} + \beta_6\text{Located floor} + \beta_7\text{Total floor} + \beta_8\text{Building type} + \beta_9\text{Proportion of elevator to households} + \beta_{10}\text{Property rights period} + \beta_{11}\text{Residential building service life} + \beta_{12}\text{Residential building use} + \varepsilon \quad (9)$$

where, β_0 and ε represent the constant and disturbance interference terms, respectively. The parameter estimation strategy comprises two steps. The first step is a full-sample regression model. We determine whether the core explanatory variable of whether an elevator exists has a significant impact on the value of the residential building. If the result of β_1 in the first step is significant, it means that the installation of elevators will have a significant impact on the unit price of the residential building. However, in certain residential buildings the elevators are installed during the construction process, and therefore, it is insufficient to only test whether the buildings are equipped with elevators. Therefore, the sub-sample, of residential buildings with elevators, is extracted to perform a regression analysis. If the result of β_1 is still significant, then installing elevators will significantly impact residential building prices. In 2014, Shanghai became the first Chinese city to issue a new version of the Residential Design Standards that mandated the installation of elevators in new residential buildings of four to six floors. Therefore, we assume that residential buildings that have elevators and were built before 2014 installed the elevators after construction. By taking a subsample of residential buildings built before 2014 with six stories or less, the net effect of adding elevators on the unit price of a residential building can be estimated. Similarly, to ensure the robustness of the results, we first examine the independent influence of the core explanatory variable on the explained variables in the subsample regression, and then incorporate the control variables into the model. The estimated results are shown in Table 4.

	Full sample regression		Subsample regression	
	Model 1	Model 2	Model 3	Model 4
Equipped with elevator	1.496***	0.555***	1.383***	0.664*
	(25.309)	(4.991)	(3.629)	(1.681)
Close to subway		-0.278***		-0.074
		(-4.024)		(-0.957)
Residential building layout		-0.091*		0.099*
		(-1.775)		(1.720)
Residential building area		0.001		0.001
		(0.825)		(0.791)
Renovation condition		0.087**		0.013
		(2.001)		(0.242)
Located floor		0.027		-0.205***
		(0.810)		(-4.934)
Total floors		0.069***		-0.079
		(14.628)		(-1.010)
Building type		1.195***		-1.958***
		(14.231)		(-2.872)
Proportion of elevator to households		-0.106***		-0.090***
		(-5.161)		(-3.842)
Property rights period		0.314***		0.119*
		(5.537)		(1.740)
Residential building service life		-0.075**		-0.015
		(-2.280)		(-0.363)
Residential building use		1.662***		
		(7.770)		
Constant	5.935***	3.011***	5.912***	8.702***
	(145.949)	(12.589)	(200.503)	(11.134)

Observed value	2,133	1,902	1,002	812
R-squared	0.231	0.444	0.013	0.098

Table 4: Summary of Stata Empirical Results

4.2 Calculation of The Price Premium Effect of Installing Elevators

In Model 1 of the full-sample regression, only the single effect of equipped elevators on residential building prices is examined, and the combined effects of other residential building characteristics are considered in Model 2. The coefficients of equipped elevators are significantly positive as are the coefficients of adding elevators, when only the installation of elevators is considered. Therefore, the average unit price of apartments in residential buildings with elevators is higher than in buildings without elevators. This result holds whether it is only the single effect of installing elevators on the residential building price in Model 3, or the joint effect of considering other characteristics of the residential building in Model 4.

Furthermore, the regression results of the control variables identify other characteristics that affect the unit price of apartments in residential buildings. For example, the proportion of elevator households and the age of the residential building are significantly negative. In addition, the proportion of staircase households, which is the total number of households corresponding to the stairs on a particular floor, reflects the degree of living congestion on that floor. If the estimated value is negative, then the more crowded the floor, the less conducive it is to an increase in the value of the residential building. In addition, households of apartments in residential buildings that are less than five years old have stronger bargaining power in the residential resale property market compared to older buildings, which is reflected in the increase in residential building prices.

However, the influence of some factors, such as proximity to the subway, building type, area, and façade, on the unit price of residential buildings differs in the results of the various samples. For example, in the full-sample regression, the facade has a significant positive impact on the unit price of apartments, indicating that residential buildings with a quality facade are more expensive. Yet, for residential buildings with elevators, the effect of the facade is positive, but not significant. Therefore, when negotiating the price of residential buildings that have fewer than six floors, supply and demand are affected more by whether the properties are equipped with elevators than by a nice facade. Proximity to a subway shows a counterintuitive negative effect, a result that may be related to homebuyers' characteristics. An important reason for installing elevators is to facilitate access for older adults. However, the noise generated by subway commuting and road congestion during morning and evening rush hours has a greater adverse impact on their lives. In addition, when considering only residential buildings with six or fewer floors, the effect of proximity to a subway is negative but not significant. Therefore, compared to the provision of elevators, proximity to a subway plays an important role in the negotiation because of its negative effect.

The residential building price data of six-story buildings were extracted and divided into two groups: those with elevators and those without. The prices of apartments were compared in terms of lower floors (first and second floor), middle floors (third and fourth floors), and upper floors (fifth and sixth floors). The results in Table 5 show that the average prices of apartments on the middle and lower floors of the elevator group are lower than that of the corresponding apartments in the non-elevator group. Contrastingly, the prices of the middle and upper floors of the elevator group are higher than those of the corresponding apartments in the non-elevator group. The regression results in Table 4 further show that while adding elevators significantly increases the unit price of apartments, the apartments are still affected by spatial heterogeneity. Adding elevators only increases the unit prices of apartments on the middle and upper floor households, but decreases the unit prices of apartments on the lower floors. Therefore, when elevators are installed, the households on the first few floors should be exempted from paying for them; they may even be compensated financially.

Floor	Without elevator	With elevator	Difference
Lower floors	6.365	5.168	-1.197
Middle floors	6.162	7.365	1.203
Upper floors	5.776	6.428	0.652

Table 5: Profits and Losses of Residential Building Prices on Different Floors in The Elevator and Non-Elevator Groups

The results show that the price premium of installing elevators in residential buildings with different characteristics differ based on the financial externalities of the buildings' characteristics. These factors should be included in the consideration of elevator cost allocations and the critical floor further defined as the critical point for cost apportionment or compensation. The installation of elevators usually has negative externalities on the living comfort of households on the first few floors, such as ventilation, lighting, and even the unit price of their apartments. Simultaneously, elevators add much convenience for households on the upper floors in addition to the financial premiums reflected in the increase in their apartments' values. Therefore, it is vital to clearly define a critical floor as an important dividing point between compensation and apportionment.

Second, based on the degree of benefit as an important factor in cost allocation, the benefits of installing elevators to owners of the upper-floor apartments are derived from the use value of the elevator and the apartment premiums. Third, the amount of compensation for households of apartments on the lower floors is estimated indirectly by considering their willingness to install because it is difficult to quantify the damage to them directly.

4.3 Cost-Sharing Model for Installing Elevators

Based on the theoretical model of the compensation cost for the installation of elevators constructed by Ning, the four key indicators in the model are: the frequency of elevator use, residential building appreciation rate, proportion of households that agree to install an elevator, after compensation, and proportion of households that reject the proposition (Figure 2) [19].

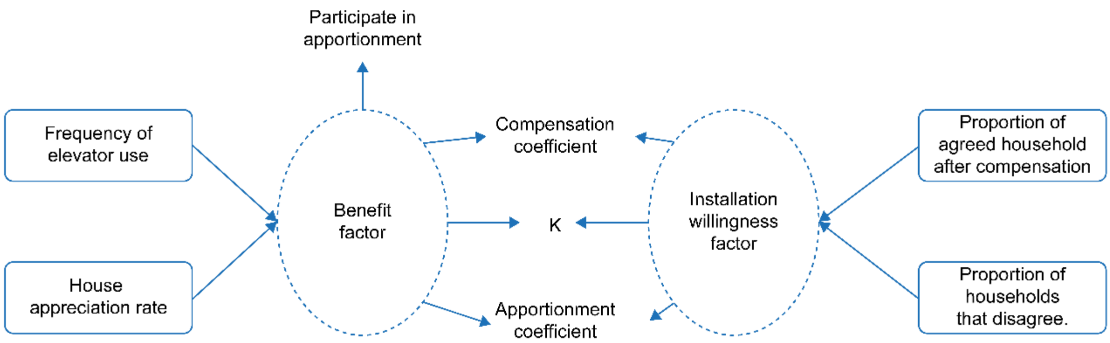

Figure 2: Standard Cost Allocation Model for Installing Elevators in Old Residential Buildings

The specific allocation method parameters are explained below and summarized in Table 6.

1. The benefit degree factor b_i is calculated by weighting the frequency of elevator use and the appreciation rate of the apartment, and it satisfies $b_i = \alpha_1 f_i + \beta_1 r_i$。 .

2. The installation willingness factor w_i is the various households' willingness to install and is a weighted value, $w_i = \alpha_2 h_i + \beta_2 u_i$。 .

3. The comprehensive factor Q_i is a weighted value based on the willingness-to-install factor w_i and the benefit-degree factor b_i.

4. The critical floor K is based on the comprehensive factor Q_i, which is satisfied if $K = \min(i), if\ Q_i > 0$. In other words, the critical floor is the lowest floor where its comprehensive influence factor is greater than zero.

5. The apportionment coefficient cc_i is used as a proxy for the allocation coefficient to satisfy $cc_i = Q_i / \sum Q_i$, i = K, K + 1,…N。 and is based on the proportion of the comprehensive factors of each floor to the total comprehensive factors of all the floors

6. The compensation coefficient is sc_i. According to the proportion of the total influencing factors applicable to all the floors participating in the compensation, sc_i is satisfied when $sc_i = Q_i / \sum Q_i$, i = 1,2,…K-1。

7. The compensation ratio δ refers to the ratio of the degree of benefit to households below the critical floor to the average degree of benefit to all households.

8. The total cost C_1 of elevator installation has two parts: the actual supply and installation costs of installing the elevator C_0 and the compensation for low-rise households C_2. Therefore, $C_1 = C_0 + C_2 = C_0 + C_1 \delta$.

9. $c1_i$ represents the average cost-sharing of the households above the critical floor, and c_{2i} represents the average compensation received by the households below the critical floor. Therefore, $c_{1i} = C_1 * cc_i$, where i = K, K+1,…N and $c_{2i} = C_2 * sc_i$, where i = 1,2,…K - 1.

Variables	Symbols	Explanations
Frequency of using elevator	f_i	Frequency of using elevator by the i^{th} floor households.
Housing appreciation rate	r_i	Apartment value premium after elevator installation.
Agreed proportion after compensation	h_i	Proportion of households that agree to install elevators after compensation.
Fully disagree proportion	u_i	Proportion of households that do not support installing elevators at all.
Benefit factor	b_i	Benefits for the i^{th} floor households from installing elevators
Installation willingness factor	w_i	The intention of the i^{th} floor households to install an elevator.
Comprehensive factor	Q_i	The impact caused by households of the i^{th} floor installing an elevator.
Critical floor	K	The floor on which the comprehensive impact factor is greater than or equal to zero
Compensation fee	c_{2i}	Compensation fees received by the i^{th} floor households.
Total floors	N	Total number of floors in the building.
Apportionment coefficient	cc_i	Proportion of expenses borne by the i^{th} floor households.
Compensation coefficient	sc_i	The proportion of the compensation cost received by compensated households of the total compensation cost.
Total cost sharing	C_1	The total cost to be shared by households above the critical floor.
Elevator installation cost	C_0	The actual cost of the elevator installation.

Total compensation	C_2	Total compensation for households below the critical floor.
Compensation ratio	δ	Proportion of compensation expenses in total apportioned expenses.
Shared expenses	c_{1i}	Actual expenses shared by the i^{th} floor households.

Table 6: Model Variables, Symbols, And Interpretations

Generally, the frequency of elevator use can be obtained by conducting a statistical survey of buildings with elevators, and the residential building appreciation rate can be obtained by comparing the prices of buildings with similar characteristics. Willingness to install and proportion of households can be obtained by conducting field interviews in the form of questionnaires. In addition, three groups of weight data α need to be determined in the model (α_1, β_1), (α_2, β_2) and (α_3, β_3) and weights can be allocated using an expert scoring method. Therefore, in this case, let $\alpha_1 = 0.23$, $\beta_1 = 0.77$; $\alpha_2 = 0.32$, $\beta_2 = 0.68$; $\alpha_3 = 0.71$, $\beta_3 = 0.29$.

Floor	**Unit**	**1st floor**	**2nd floor**	**3rd floor**	**4th floor**	**5th floor**	**6th floor**
Frequency of elevator use	%	0	7.1	17.9	21.4	25	28.6
Housing appreciation rate	%	-18.8	-18.8	19.5	19.5	11.3	11.3
Agreed proportion after compensation	%	63	26	11	0	0	0
Fully disagree proportion	%	37	45	18	0	0	0
Benefit factor	%	-14.48	-12.84	19.13	19.91	14.45	15.28
Installation willingness factor	%	45.32	38.92	18.88	13.54	9.83	10.39
Comprehensive factor	%	-23.42	-20.4	8.107	10.21	8.48	7.84
Compensation coefficient	%	53.44	46.56	0	0	0	0
Apportionment coefficient	%	0	0	23.41	29.48	24.48	22.63
Compensation or shared expense	%	8.55	7.45	17.79	22.4	18.6	17.2

Table 7: Elevator Installation Cost Allocation Details

Notes: δ=21.05%, total compensation expense=160,000 yuan, total shared expense = 760,000 yuan

The results (Table 7) show that for a six-story old residential building, the critical floor for adding elevators is the third floor. Therefore, elevator installation impairs the living comfort of households on the first and second floors and the unit price of their apartments, so the households must be appropriately compensated. The amount of compensation should be higher for those on the first floor than on the second. For the third and higher floors, elevator installation adds convenience and a price premium. Therefore, the installation costs should be shared by the households on these floors. Furthermore, those on the fourth floor should pay the most because they benefit the most, and those on the sixth floor should pay less than those on the fifth.

5. Conclusion

The installation of elevators in old residential buildings has been a major undertaking in China. With a large aging population, the need for elevators is increasingly urgent. As a quasi-public good in the community, the installation of elevators creates challenges in terms of mutual competition between stakeholders, insufficient funds, reluctance to participate, and difficulty in negotiating the compensation or cost-sharing ratios. These problems are of great interest to the government, households, and elevator service providers.

Using evolutionary game theory, this study designs an incentive mechanism for the government, based on the function simulation of the benefit-sharing coefficient with or without incentives, to balance the interests of the households and elevator service providers. The empirical research suggests that governmental financial subsidies for households of residential buildings should be much higher than those for elevator service providers to facilitate consistent choices by both groups. In addition, the higher the financial incentive paid to households, the higher the likelihood that households will choose to participate.

In addition, an empirical test was conducted based on the transaction data for the resale housing market in Hongkou District, Shanghai, from the official website of Lianjia. The installation of elevators in multistory residential buildings, especially older ones, was found to significantly positively affect the values of these properties, though at different premiums. Therefore, before installing elevators, it is necessary to not only consider cost allocations, but also to financially compensate the households residing on the lower floors. Therefore, this study determined the cost allocation or compensation for each floor through a model, and the results provide a practical reference to effective promotion and installation of elevators.

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