

Optimization of the subsidy for university faculty relocation in campus suburbanization

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Abstract: This study explores the optimal subsidy policy to maximize the benefits associated with the suburbanization of university campuses. A transport accessibility index is introduced, and a model is developed to analyze faculty housing relocation, incorporating factors such as transport accessibility, housing price, relocation subsidy, and the influence of children. The impact of housing relocation is assessed using a regional output model that considers both production and consumption aspects. Subsequently, a decision-making model is established to determine the optimal subsidy level and the number of faculty to relocate, with the overarching goal of maximizing total regional benefits. The findings reveal that an increase in subsidies correlates with a rise in the willingness of faculty to relocate, leading to heightened benefits for the region. However, the rate of benefit increase shows diminishing returns with each increment change in the subsidy. Notably, the study demonstrates that 70% of the additional benefits to the region emanate from the housing market, accurately reflecting the current financial landscape in China. This insight underscores why city governments frequently leverage land markets to actively promote suburbanization.

Keywords: Urbanization, university suburbanization, transportation accessibility, housing location, financial subsidy

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1 Introduction

In China, a prevalent strategy for fostering suburbanization involves establishing university towns on the peripheries of newly developed areas and encouraging the relocation of universities from central urban zones to these outskirts. Given that the majority of universities in China are public institutions, this facilitates the negotiation process between local governments and academic institutions. A noteworthy example is the city of Shanghai, which initiated the construction of Songjiang University Town in 2001. By 2005, this endeavor resulted in the relocation of 80,000 college students and

7,000 faculty and staff from seven universities to the university town, thereby accelerating the development of the suburban locality.

In addition to the established relationship between universities and the government in China, these institutions are characterized by their substantial sizes. On average, a typical Chinese university accommodates 20,000-40,000 students and employs approximately 3000-5000 faculty members. While students usually reside in on-campus dormitories and receive financial support from their parents, their relocation entails a shift to new dormitories without a significant increase in daily commute. Consequently, the immediate demand for efficient travel facilities for students is relatively low.

While the establishment of new university towns in the suburbs contributes to urbanization, providing more industrial and commercial land that enhances city fiscal revenue, the relocation poses challenges for university faculties. Unlike students, faculty members have heightened travel demands due to commuting, shopping, socializing, accessing recreational activities, and fulfilling family responsibilities such as education and healthcare. Given the government's limitations in providing comprehensive infrastructure in newly developed areas in the short term, faculty members face a dilemma. They must choose between relocating to areas near the new campus, allowing an easy commute but offering limited access to other social amenities, or continuing to reside in their original housing, which provides better access to amenities but hinders their daily commute.

When confronted with this decision, a majority of faculty members operating under a flexible working schedule opt to remain in their original residence, leading to a reduction in their time spent on the new campus. Statistics show that a decline in campus visits by these faculty members from 4-5 times to 1-2 times per week after campus relocation. This decline significantly diminishes opportunities for offline communication between faculty and students, thereby affecting the overall university production. To address this reluctance, municipal governments and university authorities have implemented various measures to encourage faculty either to reside in close proximity to the campus or to increase their frequency of campus visits.

A widely adopted strategy involves providing faculty with subsidies to assist in housing purchases near the new campus. This includes the provision of below-market housing or monetary subsidies for acquiring housing at market prices. Additionally, subsidies are offered to compensate faculty for the loss of transport accessibility. These subsidies pose economic challenges, however, involving input-output consideration and determining the most effective means of subsidy provision. The decision-making in this context aims to maximize subsidy utility, with utility measurement serving as is the key to its success.

In light of the challenges posed by university suburbanization, this paper examines faculty housing location behaviors, analyzes the impact of subsidies compensating faculty for the loss of transport accessibility on these behaviors, investigates the influences of housing relocation on the regional economy, and constructs an optimization model to determine the optimal subsidy level.

The contributions of this study are as follows: 1) It introduces an equation to measure the transport accessibility of a housing site based on factors such as campus access, shopping, leisure and entertainment, medical care, and elementary education, serving as a key indicator of housing utility; 2) Given this accessibility measure, faculty preferences, housing prices, and subsidy amounts, the paper constructs functions for both housing location utility and choice, facilitating the analysis of university faculty relocation to the suburbs; 3) It analyzes and describes the positive effects of faculty relocation, such as the increase in university production, stimulation of the transportation sector, and benefits to consumption and housing; 4) An optimization model is developed to determine the

optimal subsidy level, aiming to maximize the total benefit to the regional economy, with faculty participation in university activities holding a crucial role.

This comprehensive framework considers the behaviors and benefits of the faculty, the university, and the city, taking into accounts various factors associated with each party, such as faculty accessibility, faculty involvement in the university, and economic benefits for the city.

The structure of this paper is as follows: Section 2 provides a literature review; Section 3 describes the problem with a logical structure chart; Section 4 presents model construction and all the equations for calculating the intermediate variable; Section 5 outlines model solution algorithm; Section 6 includes a case analysis; and Section 7 summarizes the study and highlights significant implications. Finally, additional data are provided in Appendices A–D.

2 Literature review

This study delves into suburbanization, transport accessibility, housing location, and the impacts of university's activities on regional economy. We incorporate these four aspects into the literature review to establish the theoretical foundation for our approach and conduct a thorough analysis of the identified problems.

2.1 Literature on suburbanization

The historical analysis of the outward sprawl of urban activities to suburbs and the subsequent expansion of city areas constitutes a prominent subject in suburbanization studies. In Europe, Ouředníče (2007) focused on housing suburbanization and investigated the types of suburbanization that developed during the regional urban transformation of Prague. This research was based on migration flows recorded during 1995–2003 in various localities of the urban region around Prague. Rahel and Christian (2016) explored changes in the former “urban periphery” of Zurich North over the last three decades by drawing on expert interviews, group discussions with planners, participatory observations, and street interviews. They employed the concepts of conceived, perceived, and lived space, and developed a picture of the profound urban transformations.

While studies in Europe analyze the process of suburbanization around well-established urban centers, questions of sprawl gain particular relevance in research focused on the United States. Choi et al. (2014) answered two key questions, namely, whether Southern California had experienced or would experience any convergence in the population-employment (P-E) ratio among counties, and whether a vector auto regression method based on county-level data sets allows the development of a P-E ratio projection model. Hamidi and Ewing (2014) operationalized compactness and sprawl across four dimensions (development density, land use mix, activity centering, and street accessibility) using principal component analysis and cross-sectional data from 2010 for large urbanized areas in the U.S.

It should be noted that there have been some fruitful comparisons between urbanization processes on Europe and Northern America. Heider and Siedentop (2020) compared changes in intra-metropolitan employment patterns in two German and U.S. urban regions from 2003 to 2015. Their comprehensive, longitudinal, and international comparative perspective revealed that U.S. metropolitan areas were far more decentralized and deconcentrated than their German counterparts, showcasing a significant variety of inter-regional spatial trajectories in both countries.

Regardless of geographical focus, the contribution of literature on urban processes lies in its use of real data, including interviews, to characterize the phenomenon of urbanization and the mechanisms of suburbanization. The accuracy of the conclusions in such studies, however, depend on the quantity and precision of the collected data. In addition, these studies are typically confined to specific urban regions, and while conclusions are more accurate at the local level, their applicability to drawing macro-scale conclusions is limited.

2.2 Literature on housing location

The development of land use and transportation models is another main research avenue of suburbanization studies. Several reputable land use and transportation models (LUTMs) could be established, including DRAM/EMPAL, CATLAS, METROSIM, TRANUS, MEPLAN, and UrbanSim. Given the variety of models, the literature on LUTMs draws on theoretical and conceptual propositions from a wide range of disciplines. First popularized by Lowry (1964) in his model of a metropolis, the spatial interaction approach came from the theory of social physics. More recently, Yang et al. (2015) developed a model with the objective of optimizing the combination of employees' quality of life and the efficiency of services in newly developed suburbs. They considered the effects of factors such as commute times, housing prices, available housing stock, the location of services, and access to the CBD (central business district) on housing location choices. Wang et al. (2018) proposed a method to determine the optimal structure and scale of air transport industry clusters for a newly developed airport zone, in which Lowry model is also used to consider employees' housing location choices and the impact of available services on those choices. Schaldach and Alcamo (2007) used the HILLS model system to simulate recent (1990–2000) and future (up to 2020) changes in land use and carbon sequestration in central Germany. Osman et al. (2018) integrated the Markov chain, cellular automata, and logistic regression approaches to build a model and applied to monitor, evaluate, and predict the effects of uncontrolled urban sprawl and land-use changes in the Greater Cairo Metropolitan Region up to 2035. Zhuge et al. (2016) proposed an agent-based joint model of housing location and real estate prices, and used SelfSim to simulate the negotiation between active household agents and owner agents. They also used Baoding, a medium-sized China's city, to test the model. While many of these models draw effectively from various location theories, including agricultural, industrial, and commercial, as well as Lowry and agent-based simulation models, each is highly customized, limiting cross-application to different urban planning environments. Recognizing the idiosyncratic nature of these approaches, in this paper, we will also develop a customized model aligned with its specific objectives.

Before transitioning from LUTMS, it is worth noting that housing location and transport accessibility are the two most important variables for these models. While transport access is commonly used to measure spatial interaction intensity, the location model is frequently the focal point in LUTMs. As early as 1959, Hansen (1959) defined transport accessibility as the "potential of opportunities for interaction." Later, Ingram (1971) defined it as the "inherent characteristic (or advantage) of a site with respect to overcoming some form of spatially operating source of friction." Dalvi and Martin (1976) further categorized sources of friction in terms of an individual's ability and behavior, the spatial variation of opportunities, and the quality of the transportation system. Burns and Golob (1976) defined accessibility as the "ease with which any land-use activity can be reached from a site using a traffic mode." Thus, transport accessibility was defined as an

output of the interaction of the geographical distribution of activities with the transportation infrastructure (Páez et al., 2012).

2.3 Literature on transport accessibility

When examining accessibility, the major measures can be categorized as infrastructure-based, location-based, and person-based metrics (Marwal & Silva, 2022). In the realm of infrastructure-based approaches, Grengs (2010) built a gravity accessibility model by using the 2000 census data of Detroit. This model analyzed the differences in accessibility to jobs in different areas by different individuals, addressing calls for the reconceptualization of spatial mismatches. Karou and Hull (2014) developed a GIS-based accessibility model, known as the Spatial Network Analysis of Public Transport Accessibility, to measure the effectiveness of public transit in ensuring access to different services and activities in the City of Edinburgh. Lucas et al. (2016) found that additional transportation appraisal methods were not sufficient to capture the social dimensions of mobility and accessibility. They drew on the Lorenz curve and the Gini index to propose a method to assess the socially relevant accessibility impacts of urban policy. In the domain of personal- and location-based measures, Reyes et al. (2014) conducted a statistical analysis of trip length to calculate the access of urban children to parks using the attributes of age, gender, income class, family structure, and geographical location information published in Montreal's 2008 Household Travel Survey. In a different context, Yi (2021) used a multi-constraint model to evaluate the accessibility of primary schools in the Haishu district of Ningbo City via walking, public transit, and car, respectively, with the aim of elucidating differences in regional education equity. Sharma and Pati (2022) also developed a conceptual framework to measure access to educational services using an extensive dataset of mode-wise, travel time matrices for 577 Traffic Analysis Zones (TAZ) and 4,308 schools in Greater Mumbai. They employed the Gini index to assess the distribution of educational accessibility and spatial inequities in education.

While the literature on accessibility often concentrates on the specific activities of particular groups, there is a limited focus on measuring access to multiple household services and activities. Church and Marston (2003) proposed a theoretical method of combining the accessibility measurement of different types of activities, but did not implement it in practice. Zheng et al. (2019) distinguished between types of activities based on their relative weight on QOL (Quality of Life) and then integrated the various accessibilities of these activity types to assess overall accessibility. In this paper, we consider the diverse needs of multiple family members, initially modeling the accessibilities of commuting, shopping, elementary education, and other activities. We then derive the transport accessibility of a household through a synthesis of the individual accessibilities, using this measure as the influencing variable in the housing location model.

2.4 Literature on the impacts of universities

Turning to the practical foundation of our research project, existing literature firmly establishes that university towns play a pivotal role in catalyzing urban development and suburbanization. Goldstein and Drucker (2006) examined the impact of four-year colleges and universities in the U.S. at the metropolitan level, focusing on internal and external factors that affect regional economies and the spatial extent of these impacts. They illustrated that the greatest impacts occur in small- and medium-sized regions, and

suggested that universities may, under certain circumstances, act as substitutes for agglomeration economies. Allison and Eversole (2008) demonstrated that satellite campuses in Italy were usually built due to the needs of local governments, which bore the cost of infrastructure construction, while teachers working at these campuses contributed substantially to the local economies. Rossi and Goglio (2020) calculated the impact of a satellite campus in northwest Italy on the local economy using the sector-multiplier method, and showed that these campuses developed local human capital and stimulate the demand for goods and services in the region. Felsenstein (1996) conceptualized the impact of a university in metropolitan area as a series of backward (expenditure) and forward (knowledge-related) linkages, and estimated their effects on regional economic well-being. The study also explored spatial spillovers from universities and other economic activities in nearby regions.

In China, university towns have assumed a particularly crucial role in urbanization. In the first decade of the 21st century, over 100 university towns were built across China, highlighting the land-centered, speculative urbanism that lies at the heart of post-reform China (Li et al., 2014). Based on an ethnographic survey of Guangzhou University Town, Li et al. (2014) sought to explain the detailed political-economic reasons for the project, to decipher the roles played by various stakeholders (such as local governments), and to evaluate the effects on local communities. Shen (2022) focused more broadly on the role of university towns in China's (sub)urbanization. Based on statistical data, they recognized that the spatial expansion of universities was an integral component of capital accumulation strategies, which allowed universities to function as a financing vehicle for (sub)urban development. Ruoppila and Zhao (2017) examined the role of universities in the development of university towns through a case study based on four interviews with key figures in the development of Songjiang University Town, constructed from 2000–2005 at the outskirts of Shanghai. Wu (2008) analyzed university suburbanization in Chengdu (China) and showed that university suburbanization played a key role in promoting the urbanization of the local population, economy, culture, and residential environment on the city's outskirts through a questionnaire survey. Xia (2012) explored the effects of university suburbanization on overall suburbanization, concluding that universities generally promote the urbanization of populations and economies at the outer metropolitan edges. Luo (2008) studied the relationship between the construction of a university town and the growth of the nearby real estate market, using the example of Zijingang Campus of Zhejiang University. The encouragement of university faculty to settle near the campus led to rising housing prices and government land financing, enhancing the residential environment and providing high-quality educational resources.

While the numerical analysis of the effects of university construction or relocation on cities is well-established in the literature, there is a scarcity of theoretical analyses or attempts at policy optimization. In this paper, we construct a regional production model based on faculty's housing relocation behaviors to optimize the subsidy level and the number of faculty encouraged to relocate. The objective of the model is to maximize the total regional economic benefit by considering the interaction of feedback between government subsidies, faculty's on-campus working hours, university production, and the overall regional benefit.

3 Problem description

Figure 1 illustrates the comprehensive framework of the problem, particularly highlighting the logical relationship among the three components: faculty housing location, its impacts, and subsidy amount. Further details are expounded below.

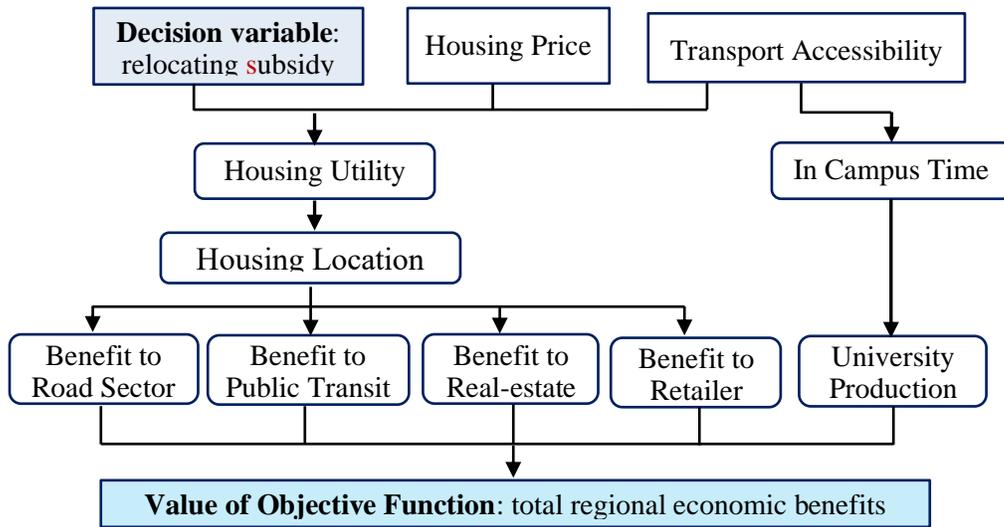


Figure 1. The components of housing factor, housing utility, and incurred benefits.

3.1 Faculty housing location

When determining the accessibility of a proposed family housing location, we must distinguish between the individual accessibilities of commuting, shopping, leisure and entertainment, medical care, and elementary education (Grengs, 2010; Elldér, 2014). When a campus is relocated to a suburb, faculty members are confronted with the dilemma of choosing between relocating near the new campus for the convenience of commuting or prioritizing the accessibility of other facilities and services that may diminish in the newly developed outskirts. Logically, post campus relocation, faculty members will decide whether to move based on the principle of random utility maximization.

3.2 The impact of faculty relocation

The decision of faculty members to relocate to the new campus is likely to promote the economic growth of the suburbs due to labor factors influencing regional production. Specifically, the educational and research activities of the faculty will directly increase university production. In terms of consumption, faculty and their family members will also promote regional growth by contributing to the overall increase in regional consumption. From the perspective of both production and consumption, the effects of faculty relocation can be categorized into four groups, each of which warrants a corresponding analysis. These categories encompass university production, the revenue generated for providers of road infrastructure and bus services, faculty’s consumption of daily goods and services, and their housing purchases within the new area.

3.3 Subsidy level

To incentivize faculty relocation around the new campus, governmental subsidies are necessary because of the need to compensate faculty for the loss of accessibility to other resources. Economic analysis predicts that a decrease in the marginal number of relocated faculty with an increase in the subsidy amount, while the marginal benefit diminishes as the number of relocated faculty rises. Consequently, the primary goal of the government is to establish an optimal subsidy level. This paper constructs a subsidy decision-making model specifically for this purpose, aiming to optimize the subsidy level with the objective of maximizing regional economic benefits.

4 Model building

4.1 Faculty housing location model

We employ a MNL (multi-nominal logit) model to describe faculty housing relocation behavior. For the construction of the housing relocation model, a study area will be divided into TAZs. We denote $j \in J = \{1, 2, \dots, m\}$ as the zones around the new campus and $i \in I = \{1, 2, \dots, n\}$ as the zones within the central city. The probability of faculty t choosing zone l ($l \in I \cup J$) to live in can be represented as:

$$P_{tl} = \text{Exp}(V_{tl}) / \sum_{l' \in I \cup J} \text{Exp}(V_{tl'}) \quad (1)$$

Here, V_{tl} is the direct utility of faculty t choosing to live in zone l , which is determined by zonal accessibility, housing price, faculty's personal attributes, and the level of subsidy. Equation 1 indicates that faculty will weigh the transport accessibility, housing prices, and their own preferences when choosing a place to live (Guiliano & Narayan, 2005). Then, the following utility function can be given:

$$V_{tl} = \begin{cases} \alpha_1 A_l + \alpha_2 H_l + \alpha_3 S + \alpha_4 C e_t + \delta, & l \in J \\ \alpha_1 A_l + \alpha_2 H_l + \alpha_4 C e_t, & l \in I \end{cases} \quad (2)$$

Here, A_l is the transport accessibility of zone l ; H_l is the housing price in zone l ; S is the relocation subsidy; $C e_t$ gives the number of children of faculty t enrolled in primary and secondary schools; finally, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \delta$ are the calibrated parameters.

If the number of faculty is N , the number of faculty members who move to live near the new campus or remain at their original homes are represented by N_m and N_{um} , respectively. Then, the transport accessibilities of these respective zones (A_l) can be calculated as:

$$N_m = \sum_{t \in N} \sum_{l \in J} P_{tl} \quad (3)$$

$$N_{um} = N - N_m \quad (4)$$

$$A_l = \theta_c A_{l,c} + \sum_{b \in B} \theta_b A_{l,b} \quad b \in B = \{1, 2, 3, 4\} \quad (5)$$

Here, $A_{l,c}$ is commute accessibility, while $A_{l,1}, A_{l,2}, A_{l,3}, A_{l,4}$ are respectively the accessibilities of shopping, leisure and entertainment, medical care, and elementary education; $\theta_c, \theta_1, \theta_2, \theta_3, \theta_4$ give the calibrated parameters.

Since the attractiveness of faculty's workplace (the campus) is fixed, here the commute accessibility is expressed only in terms of total generalize commuting travel cost, according to Lu et al. (2009), it can be measured by the reciprocal of traffic impedance from the home to the workplace, as shown below:

$$A_{l,c} = 1/C_{l,c} = 1/[\sum_m \lambda_{lm,c} \times (F_{lm,c} + T_{lm,c} \times \text{Vot})] \quad (6)$$

Here, $F_{lm,c}, T_{lm,c}$ are the travel cost and time of a faculty member from zone l to the campus via traffic mode m ; $\lambda_{lm,c}$ is the probability of a faculty member commuting from zone l to the campus via traffic mode m . Vot is the value of a faculty member's time, which can be estimated using the wage-income method.

Based on the concept of opportunity accessibility, the accessibilities of shopping, leisure and entertainment, medical care, and schools refer to the opportunities provided at trip destinations and the generalized cost to reach these destinations. These measures can then be calculated according to Ben-Akiva and Lerman (1985), as shown below:

$$A_{l,b} = \text{Ln} \sum_{l' \in I \cup J} \text{Exp}(V_{ll',b}) \quad b \in B = \{1,2,3,4\} \quad (7)$$

Here, $V_{ll',1}, V_{ll',2}, V_{ll',3}, V_{ll',4}$ are, respectively, the utilities derived from access to amenities in zone l' by faculty living in zone l . According to Bhat et al. (2002), these utilities can be calculated as follows:

$$V_{ll',b} = w_1 \text{Ln} D_{l',b} - w_2 \text{Ln} C_{ll'} \quad b \in B = \{1,2,3,4\} \quad (8)$$

Here, $D_{l',1}, D_{l',2}, D_{l',3}, D_{l',4}$ are, respectively, the service levels of stores, leisure and entertainment facilities, medical clinics, and elementary schools; $C_{ll'}$ is the generalized cost of traveling from zone l to zone l' ; w_1, w_2 are parameters, that will be calibrated using SP- or RP-survey data.

$$D_{l',b} = \text{FN}_{l',b} / \text{FN}_b \quad b \in B = \{1,2,3,4\} \quad (9)$$

$$C_{ll'} = \sum_m \lambda_{ll'm} \times (F_{ll'm} + T_{ll'm} \times \text{Vot}) \quad (10)$$

Here, $\text{FN}_1, \text{FN}_2, \text{FN}_3, \text{FN}_4$ are, respectively, the total sales space of retail stores, the size of leisure places (parks, restaurants, and entertainment spaces), the number of doctors in hospitals, and the number of teachers at primary and secondary schools in the entire study area. $\text{FN}_{l',1}, \text{FN}_{l',2}, \text{FN}_{l',3}, \text{FN}_{l',4}$ are, respectively, these factors located in destination zone l' .

4.2 Economic output model

4.2.1 University production

To quantify the total output of a university based on the Cobb-Douglas production function (Denison, 1962), we initiate the analysis by considering educational production as the dependent variable. The technological level, the amount of educational capital, and the faculty labor force are identified as independent variables in this context. The production function of the education industry can then be written as:

$$Y = EK^\phi [f(L)]^{\phi_2} \quad (11)$$

Here, Y is the output of the education industry, denoting the GDP of the regional education sector. E stands for the constant reflecting the technological level; K signifies the total fixed assets within the education industry, which can be measured by the present value of the regional investment in educational assets. $f(L)$ is the labor input. ϕ_1, ϕ_2 are the elasticities of educational capital and labor inputs to university production, respectively. In this study, schools are divided into five categories, namely, primary and secondary school, senior high school, vocational school, junior college, and university. The labor input of each category is calculated separately, as shown below:

$$f(L) = \sum_{d \in D} L_d \times T_d \times G_d + N_m \times T_m \times G_5 + N_{um} \times T_{um} \times G_5 \quad d \in D = \{1, 2, 3, 4\} \quad (12)$$

Here, L_1, L_2, L_3, L_4 are, respectively, the number of full-time faculty and teachers working in schools, colleges, and universities, and T_1, T_2, T_3, T_4 are their working hours. T_m, T_{um} are the on-campus working hours of university faculty who move or do not move to the new campus region, respectively. G_1, G_2, G_3, G_4 are the contribution weights of each type of school, which can then be represented by faculty wages (Yu, 1985) as shown in Equation 13:

$$G_d = a_d / \bar{a} \quad d \in D = \{1, 2, 3, 4, 5\} \quad (13)$$

Here, a_1, a_2, a_3, a_4, a_5 are the average wages of the faculty and teachers in each type of schools, and \bar{a} is the average wage of the five categories of faculty.

In contrast to teachers in primary and secondary schools, senior high schools, and vocational schools, faculty members at Chinese universities are not required to be on campus when they do not have lectures scheduled. Thus, the regularity of university faculty visiting the campus for teaching is closely linked to their consideration of commute accessibility. Opting to live near the new campus enhances commuting convenience, inevitably increasing the time university faculty spend working on campus and elevating their labor input. Assuming the labor input of other teachers remains constant, the additional value in the educational product resulting from the increased labor input of relocated university faculty can be viewed as the production benefit of the university. When choosing to live near the new campus, with improved commute accessibility, the labor input of university faculty changes from $f(L)$ to $f(L')$, and the educational production changes from Y to Y' . Thus, the additional production of the university can be calculated as:

$$\Delta Y = Y' - Y \quad (14)$$

4.2.2 Benefits incurred in the transportation sector

Following housing relocation, the distances traveled for shopping, leisure and entertainment, medical care, and children's education are significantly extended due to the new housing sites being situated in a post-development suburb. This surge in travel distances elevates their reliance on roads and buses, contributing to increased demand. The benefits to the transportation sector arise from the provision of road infrastructures and other transit services, which are deemed public goods (Lakshmanan et al., 2001).

Given this circumstance, the depreciation of transportation assets due to heightened user demand could be regarded as a benefit accruing to the transportation sector, along with the profit from the sale of consumed fuel.

$$\Delta TC = R_D + T_D + F_P \quad (15)$$

Here, ΔTC is the overall benefits accrued in the transportation sector; R_D and T_D denote the depreciation amounts of road and bus assets, respectively; F_P is the sale profit of the additionally consumed fuel.

The unit depreciation of road assets is equal to the ratio of annual investment per unit length of road to the total traffic volume during the road's life span (Shi, 2006). The depreciation of road assets due to additional vehicle traffic is thus the product of additional vehicle travel mileage and the unit depreciation of road assets, which can be calculated as follows:

$$R_D = Dpv \cdot N_m \cdot \sum_b \sigma_{c,b} \cdot d_b \quad b \in B = \{1,2,3,4,5\} \quad (16)$$

$$Dpv = \overline{IR} / lf_{rd} / V_t \quad (17)$$

$$\overline{IR} = \sum_{r \in R} IR_r / \sum_{r \in R} d_r \quad (18)$$

Here, Dpv is the unit depreciation of road assets; $\sigma_{c,1}, \sigma_{c,2}, \sigma_{c,3}, \sigma_{c,4}, \sigma_{c,5}$ indicate the number of additional motor-vehicle trips of shopping, leisure and entertainment, medical care, childhood education, and faculty commuting, respectively. d_1, d_2, d_3, d_4, d_5 are the corresponding travel distances; lf_{rd} is the average life span of the road; V_t is the total vehicle traffic flow on the road during its life span; IR_r is the investment in road r ; R is the set of all roadways in the area; and, \overline{IR} is a unit amount of road investment.

Similarly, the depreciation of bus transit assets due to newly added passengers can be calculated as follows:

$$T_D = Dpp \cdot N_m \cdot \sum_b \sigma_{pt,b} \quad b \in B = \{1,2,3,4,5\} \quad (19)$$

$$Dpp = I_T / Pn / lf_{pt} \quad (20)$$

Here, Dpp is the unit depreciation of bus transit assets; $\sigma_{pt,1}, \sigma_{pt,2}, \sigma_{pt,3}, \sigma_{pt,4}, \sigma_{pt,5}$ are the number of personal bus trips, respectively, for shopping, leisure and entertainment, medical care, children's education, and faculty commuting. Pn is the projected total number of bus passengers; I_T represents the total cost of offering extra bus service; lf_{pt} is the life span of a bus transit facility. The profit from the sale of the extra fuels consumed includes the profits of petrol stations, oil dealers, and oil refineries, which can be calculated as:

$$FP = N_m \cdot \sum_{b \in B} \sigma_{c,b} \cdot d_b / 100 \cdot F_c \cdot F_p \cdot (pr_1 + pr_2 + pr_3) \quad (21)$$

Here, F_c is the fuel consumption per motor-vehicle per 100 km; F_p is the fuel price; pr_1, pr_2, pr_3 are, respectively, the profit margins of gas stations, oil dealers, and refineries.

4.2.3 Benefits incurred in the consumer market

Based on the land-use model, we divide the local social and economic entities into three categories, namely, basic industry, non-basic industry, and residents (Goldner, 1971). In examining the shifts in consumer markets around the new campus after the relocation of faculty members, the relocated universities may be taken as a basic industry. The service sector (e.g., wholesale and retail stores, entertainment and leisure facilities, banks and post offices, etc.) and public institutions (including primary and secondary schools, social welfare facilities, etc.) fall under the classification of non-basic industry. Since the employees in the basic industry are consumers of services from the non-basic industry, the number of employees in service sector N_{cs} and the number of employees in public institutions N_{ps} can be calculated based on the number of employees in the basic industry, as shown below:

$$\alpha = Pop / N_t \quad (22)$$

$$\beta = N_{cs} / Pop \quad (23)$$

$$\theta = N_{ps} / Pop \quad (24)$$

$$N_t = N_m + N_{cs} + N_{ps} \quad (25)$$

Here, N_t is the total number of employees, and Pop is the total regional population. Then, α, β, θ indicate, respectively, the service rate per unit employee, the number of employees in the service sector as a proportion of the total population, and the number of employees in public institutions as a proportion of the total population.

Since we only consider the marginal change in consumption due to faculty relocation, by considering the number of relocated faculty as the number of employees in the basic industry, we can then calculate the total population and the number of employees in the non-basic industry as:

$$Pop^{(1)} = \alpha N_m \quad (26)$$

$$N_{ps}^{(1)} = \beta Pop^{(1)} \quad (27)$$

$$N_{cs}^{(1)} = \theta Pop^{(1)} \quad (28)$$

$$N_s^{(1)} = N_{ps}^{(1)} + N_{cs}^{(1)} = (\beta + \theta) Pop^{(1)} = \alpha(\beta + \theta) N_m \quad (29)$$

$$Pop^{(2)} = \alpha N_s^{(1)} = \alpha^2 (\beta + \theta) N_m \quad (30)$$

The numbers in the superscript parentheses indicate the number of calculation iterations. The additional population in the second iteration also require services from the non-basic industry. Thus, this iteration will cause a further increase in the number of people employed in the non-basic industry. The number of newly added employees in the non-basic industry can be calculated as:

$$N_s^{(2)} = N_{ps}^{(2)} + N_{cs}^{(2)} = \alpha^2 (\beta + \theta)^2 N_m \quad (31)$$

The total number of employees will be the sum of the number of people employed in the non-basic industry during the entire calculation process, and the number of initial employees, as shown below:

$$N_t = N_m + N_s^{(1)} + N_s^{(2)} + N_s^{(3)} + \dots \quad (32)$$

Equation 34 can then be obtained by substituting Equation 30 and Equation 31 into Equation 33, as follows:

$$\begin{aligned}
N_t &= N_m + \alpha(\beta + \theta)N_m + \alpha^2(\beta + \theta)^2 N_m + \alpha^3(\beta + \theta)^3 N + \\
&= N_m [1 + \alpha(\beta + \theta) + \alpha^2(\beta + \theta)^2 + \alpha^3(\beta + \theta)^3]
\end{aligned} \tag{33}$$

Finally, we use Equation 35 to calculate the total number of employees, and Equation 36 to calculate the total residential population in the region as shown below:

$$N_t = N_m [1 - \alpha(\beta + \theta)]^{-1} \tag{34}$$

$$Pop = \alpha N_m [1 - \alpha(\beta + \theta)]^{-1} \tag{35}$$

When measuring the benefits stemming from increased household consumption, goods and services are divided into food, clothes, housing, necessities and services, transportation and communication, education and entertainment, and health care. By using $P_{n,p}$ as the percentage of household spending for goods n relative to their total expenditure, and $P_{n,p}^k$ as the percentage of household spending in zone k for goods n relative to their total outlay for goods n , then the benefit incurred in the consumption market can be expressed as:

$$\Delta Co = Pop \times Ac_w \times \sum_n \sum_k P_n \times P_n^k \tag{36}$$

Here, ΔCo is the benefit incurred in the consumer market, and Ac_w is the per capita consumption expenditure.

4.2.4 Benefits incurred in real estate market

The relocation of faculty housings leads to population increases around the new campus. The collective relocation of faculty, which occurs over a short period of time, may result in an increase in housing prices due to a sharp rise in real estate demand. Of more concern is that this temporary surge in demand may trigger a Matthew effect, inducing a relatively long-term boom in the housing market. During this brief period, new home buyers include faculty (N_m) and the additional individuals (N_s) employed in the non-basic industry who are willing to live in the same area. The demand for housing stock from these two groups are $B = N_m \times M_m$ and $C = N_s \times M_s$, respectively, where M_m, M_s are the average housing floor area occupied by faculty and non-basic industry employees, respectively.

In order to measure the benefits incurred in the housing market, it is necessary to analyze the changes in demand within the housing market. In Figure 5, D_1, D_2 are the housing demand curves in the area around the new campus before and after faculty relocation, while S is the corresponding supply curve. Population migration produces an increase in housing demand, so the demand curve will shift right to D_2 , while supply curve S will remain unchanged in the short-term, and the housing price will rise from hp_a to hp_l . Assuming that both the supply and demand curves are linear, then the gain in the housing market is equal to the sum of the total floor area of available housing before the relocation multiplied by the increase in the housing price, plus the new housing demand multiplied by the corresponding housing price after the relocation. This is equivalent to the shaded area of the graph shown in Figure 2, and can be calculated as follows:

$$\Delta H = Q \times (hp_l - hp_a) + (B + C) \times hp_l \tag{37}$$

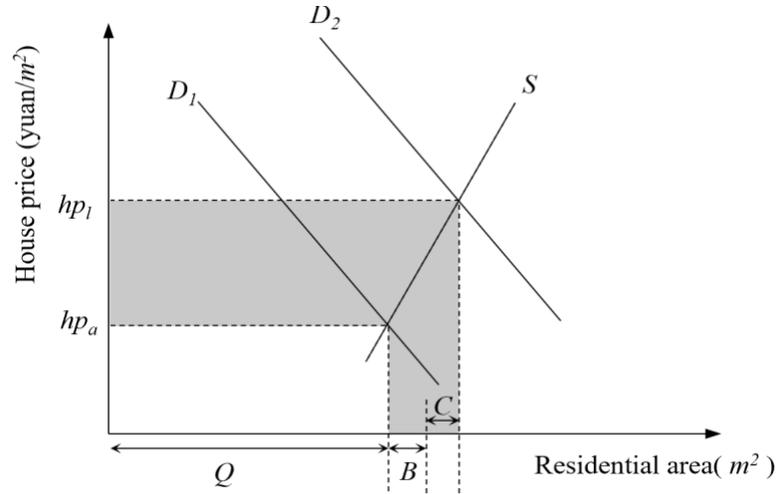


Figure 2. Changes in supply and demand in the housing market.

Here, Q is the total floor area of the available housing sold before faculty relocation. Due to the short-term lack of elasticity in the housing supply, faculty relocation will stimulate the capitalization of housing (Bauer et al., 2017) and lead to a demand bubble in investment and consequent housing price increase. Due to the imbalance between supply and demand in the housing market, the following housing price model can be constructed using differences-in-differences (DID) method, in which population is the explanatory variable, faculty relocation behavior is the dummy variable, and the distances to the nearest urban rail station, and medical and shopping facilities act as control variables. This can be expressed mathematically as follows:

$$\ln(hp_{jt}) = \beta Mo_j \times Af_t + \beta_1 Pop_{jt} + \beta_2 X_{jt} + \sum_{n=1,2} \lambda_n T_{jt}^n + \gamma \quad (38)$$

On the left side, $\ln(hp_{jt})$ is the natural logarithm of the housing price in zone j in year t after a unit of faculty relocates their residence. On the right side, Mo_j is the dummy variable of the relocation. If faculty members move into zone j , the variable is equal to 1; otherwise, it is 0. Af_t is also a dummy variable, indicating that if university faculty move to live around the new campus in year t , the variable's value is 1 from year t and beyond; otherwise, its value is 0.

The cross term of Mo_j and Af_t shows the impact of housing relocation on real estate prices. Pop_{jt} is the annual residential population in zone j ; X_{jt} is the distance from zone j to the nearest urban rail station. T_{jt}^1 indicates whether there is a hospital within 1 km, and T_{jt}^2 denotes whether there is a shopping mall within 1 km. If these facilities are available within the specified distance, the values are equal to 1; otherwise, they are equal to 0.

From the above analysis, it can be demonstrated that the benefits incurred in the housing market due to faculty relocations can be calculated as follows:

$$\Delta H = Q \times (hp_1 - hp_a) + (N_m \times M_m + P_s \times N_s \times M_s) \times hp_1 \quad (39)$$

Here, P_s is the ratio of employees in the non-basic industry purchasing housing in the area to the total number of employees in the stores.

4.3 Optimal subsidy model

The number of faculty choosing to relocate is positively correlated with the subsidy, leading to incremental regional benefits with their relocation. However, the rate of this increase, or the marginal benefits, gradually decreases as more faculty move closer to the new campus. In order to effectively promote the development of the new district, it is necessary to consider the relationship between the subsidy and the marginal benefits to the region. Moreover, when developing new districts, the government must offer essential infrastructure such as roads, public transit, gas, water and sewage, electricity, health care facilities, and schools. In this context, aiming to maximize the total net benefit of regional development (additional benefits minus government's financial expenditure), the subsidy optimization model can be established as follows:

$$\text{Max} : Z = \Delta Y + \Delta TC + \Delta Co + \Delta H - C_m \quad (40)$$

$$\text{S.T.}: N = N_m + N_{um} \quad (41)$$

$$N \leq N_{max} \quad (42)$$

$$S_{min} \leq S \leq S_{max} \quad (43)$$

Here, Z is the total net benefits in the area around the new university campus; C_m is the investment required for constructing the essential infrastructure for the area, which may be determined in accordance with municipal regulations. Finally, S_{min} and S_{max} are the upper and lower limits of the relocation subsidy levels, respectively.

5 Model solution

The above model comprises a system of nonlinear, multivariate, multivariable equations. These functions describe the interaction and feedback between subsidy amount, relocation probability, and university production. Solving such a model usually requires a heuristic method, and here is a solution algorithm:

Step 1: Let $n=0$ and let S^n be an initial value;

Step 2: Let $k=0$, and calculate $P_m^{k,n}$ using Eq. 1 – Eq. 10;

Step 3: Calculate $\Delta Y^{k,n}$, $\Delta TC^{k,n}$, $\Delta Co^{k,n}$ and $\Delta H^{k,n}$ using Eq. 11 – Eq. 39;

Step 4: Calculate $Z^{k,n}$ using Eq. 40 – Eq. 43;

Step 5: Let $k=k+1$; calculate $hp^{k+1,n}$ by using Eq. 31, then calculate $P_m^{k+1,n}$ by using Eq. 1 – Eq. 10;

Step 6: Verify the convergence; if $W = |(P_m^{k+1,n} - P_m^{k,n}) / P_m^{k,n}| \leq \varepsilon$ (here ε is a preset threshold), then output results and terminate the calculation. Otherwise, go to Step 7.

Step 7: Let $n=n+1$; enter the value of S^{n+1} and return to Step 2 and continue the calculation until $S^{n+1} = S_{max}$.

For model solution, we employed Python to program the algorithm and ran it on an average computer (Intel Ace I 5 12500/ DDR4 8G /256G).

6 Case study

6.1 Example selection and data

We conducted a case study on the relocation of three colleges from a university in central Ningbo, China. In 2018, these three colleges, out of a total of 12, were relocated to Meishan Island, approximately 40 km outside of central Ningbo. The relocated three colleges consist of 3,300 students and 400 faculty members. Figure 3 illustrates the locations of the two campuses, the road network, housing zones, current faculty housing sites, hospitals, schools, shopping malls, and leisure and entertainment places within the study area.

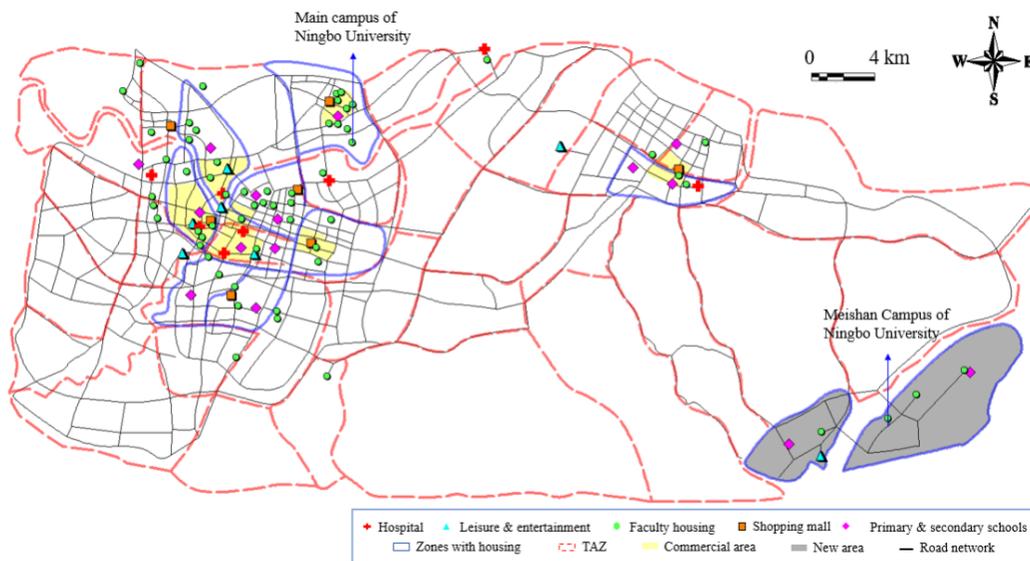


Figure 3. Map of the study area

Additional data used for the calculations in this case study are drawn from *Chinese Statistical Year Book–2020*, *Ningbo Statistical Yearbooks* published from 2010 – 2020. Housing prices are derived from the websites of several real estate trading companies. Tables 1–4 show the values of some of input variables.

Table 1. The values of parameters concerning the university.

Explanation of Parameter	Parameter Value
Working hours and monthly wages of teachers	$T_1 = 8 \text{ h/d}$, $a_1 = 6700 \text{ Yuan}$
in primary school and middle school	$T_2 = 10 \text{ h/d}$, $a_2 = 8031 \text{ Yuan}$
Working hours and monthly wages of teachers	$T_3 = 8 \text{ h/d}$, $a_3 = 7153 \text{ Yuan}$
in vocational school and junior college	$T_4 = 8 \text{ h/d}$, $a_4 = 8600 \text{ Yuan}$

Working hours and monthly wages of a relocated faculty member at the new campus	$T_{um} = 52$ h/w, $a_5 = 12000$ Yuan
Working hours and monthly wages of a non-relocated faculty member at the new campus	$T_m = 31.2$ h/w, $a_5 = 12000$ Yuan

Source: “Ningbo Statistical Yearbooks” published from 2010 – 2020. While T_m and T_{um} are from self-survey.

Table 2. The values of parameters concerning the transportation sector.

Explanation of Parameters	Parameter Value
Construction cost per unit of roadway;	$\overline{IR} = 29$ million Yuan
Total cost per route of bus transit	$IPT = 89.52$ million Yuan
The life cycles of roadways and bus transit facilities	$l_{fd} = 15$ year, $l_{pt} = 7$ year
Daily road traffic flow	$V_r = 26,915$ PCU/Day
Daily bus passenger volume	$Pn = 7,168$ persons/Day
Car fuel consumption per 100 km, Fuel price	$F_c = 10.5$ L, $F_p = 8.4$ Yuan/L
Profit margins of gas stations, oil dealers, and oil refineries	$pr_1 = 12.3\%$, $pr_2 = 0.31\%$, $pr_3 = 2.38\%$

Source: Authors’ estimation based on “Road construction code,” some collected “Highway construction project financial report,” “Bus company’s annual reports,” “Urban Traffic Survey,” etc.

Table 3. The values of parameters concerning the consumption market.

Explanation of Parameter	Parameter Value
Service rate per unit employee	
Employees in service sector / total population	$\alpha = 1.596$, $\beta = 0.315$, $\theta = 0.159$
Employees in public institutions / total population	
Per capita consumption expenditure	$Ac_w = 38,274$ Yuan

Source: Chinese Statistical Year Book–2020

Table 4. The values of parameters concerning the housing market.

Explanation of Parameters	Parameter Value
Housing area of a relocated faculty member Housing area of an employee in non-basic industry	$M_m = 100 m^2, M_s = 57.8 m^2$
Total housing area in the study area	$Q = 62870 m^2$
The percentage of employees in non-basic industry purchasing housing in the new district	$P_s = 28\%$

Source: Authors' filed survey and interview.

6.2 Model calibration

6.2.1 SP Survey on faculty relocation

For calibrating the housing utility function (Equation 2), we conducted a SP survey involving 180 faculty members out of the total 310 faculty. Participants were presented with four subsidy options: 40, 70, 110, and 140 thousands RMB per faculty per year, and they were asked to indicate their housing location preferences, i.e., remaining in their original housing or relocating near the new campus. Table 5 presents the descriptive statistics of the survey data.

Table 5. The descriptive statistics of survey and collected data.

Attributes	Distribution	Value
Gender	Male	55.03%
	Female	44.97%
Number of children in primary or secondary schools	2	4.13%
	1	11.2%
	0	84.67%

6.2.2 Model of faculty's housing relocation

The logit model was calibrated based on housing prices, faculty's housing location preferences, and the transport accessibility of faculty members working at the new campus. The calibration results are shown below in Table 6 and Equation 44.

Table 6. Calibration results of utility functions.

Parameter	δ	α_1	α_2	α_3	α_4
Value	-4.264***	1.97***	-1.85***	1.359**	-1.67***
<i>t</i> -value	-3.19	2.96	-2.61	2.32	-3.04

Note: ***, ** and * indicate significance levels of 1%, 5%, and 10%, respectively.

$$V_{it} = \begin{cases} 1.97A_l - 1.85H_l + 1.359S - 1.67Ce_l - 4.264, & l \in J \\ 1.97A_l - 1.85H_l - 1.67Ce_l, & l \in I \end{cases} \quad (44)$$

The significance test levels of the calibrated parameters are all less than 0.05, indicating a confidence level exceeding 95%. From Table 5, the values of α_1, α_3 are positive and those of α_2, α_4 are negative, indicating several key characteristics of faculty relocation choices. First, when transport accessibility and the subsidy remain constant, higher housing price around the new campus corresponds to a lower probability of relocation to that area. Second, with constant housing prices and subsidy, greater transportation accessibility increases the probability of relocation. Third, when the transport accessibility, housing price, and subsidy remain constant, faculty members with children enrolled in school exhibit a lower probability of choosing to relocate.

6.2.3 The production function of the education industry

The production level of the education industry in 2019 and 2020, as well as the amount of accumulated investment in fixed educational assets and the number of teachers employed in Ningbo’s 10 administrative districts, are listed in Annex 1. In order to calibrate Equation 11, we take its logarithm and derive Equation 45. The calibration results are shown in Table 7 and Equation 46.

$$\ln Y = \ln E + \phi_1 \ln K + \phi_2 \ln[f(L)] \quad (45)$$

$$Y = 0.525K^{0.615}[f(L)]^{0.429} \quad (46)$$

Table 7. Calibration results of the production function of the education industry.

Parameter	E	ϕ_1	ϕ_2	R^2	<i>Adjust</i> R^2
Value	0.525**	0.615**	0.429**	0.998	0.998
<i>t</i> -value	3.622	3.805	2.587		

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

The fitting accuracy of $R^2 > 0.8$ indicates that technological level, educational capital inputs, and the labor force inputs can effectively explain the output of the education industry, demonstrating a high level of model fitness. Additionally, the absolute values of all *t*-values listed in Table 7 being greater than 2 indicates a 95% confidence level for the regression parameters.

6.2.4 Housing price model

Housing price data collected from 2010–2020 in the areas surrounding 18 universities in 10 China's cities are obtained from the real estate transaction website (www.zu.anjuke.com) and listed in detail in Appendix B. As test data, we utilized housing prices recorded in the areas near 7 university campuses that have relocated (either completely or partially) to remote areas over the last 10 years. These campuses include Ningbo University, East China University of Science and Technology, Shanghai Maritime University, Zhengzhou University, Henan University of Technology, China Medical University, Tianjin University of Science and Technology. The housing prices recorded near the remaining 11 universities are treated as control data, which we use to calibrate Equation 38 and produce Table 8.

Table 8. Calibration results of the housing price model.

Parameter	β	β_1	β_2	λ_1	λ_2	γ	R^2	<i>Adjust</i>
Values	0.093**	0.035**	-	0.403**	0.315**	9.298**	0.820	0.804
<i>t</i> -values	5.649	2.519	-4.370	4.029	2.722	50.174		

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

The fitting accuracy ($R^2 > 0.8$) of the housing price model attests to its robustness, with faculty relocation, population migration, distances to the nearest rail station, and the availability of hospitals and shopping malls within 1 km explaining housing prices effectively. Furthermore, the absolute values of all the *t*-values exceeding 2 indicates a 95% confidence level for the regression. The finalized housing price model can be written as follows:

$$\begin{aligned} \ln(hp_{ijt}) = & 0.093Mo_{ij} \times Af_t + 0.035Pop_{jt} - 0.018X_{jt} + 0.403T_{jt}^1 + \\ & 0.315T_{jt}^2 + 9.298 \end{aligned} \quad (47)$$

It is crucial to highlight the positive impact of faculty relocation on housing prices in the destination area, as evidenced by the coefficient 0.093 of $Mo \times Af$. In practical terms, this suggests that, in year *t*, housing prices will experience a 9.3% increase due to faculty relocation. Conversely, the coefficient of the distance to the nearest rail station being -0.018 implies that a 1 km increase in the distance between residential areas and the nearest rail station leads to a 1.8% decrease in housing prices.

6.3 Analysis of calculation results

Utilizing Equation 1, we calculated the relocation probability of each faculty cluster. Figure 4 shows the number of faculty willing to relocate given different subsidy levels, highlighting an increasing trend as the subsidy level rises. When the subsidy reaches 140,000 Yuan/Person/Year, all 400 faculty members express willingness to relocate to the new campus area. According to Equation 35 and Equation 36, the total number of employed persons (N_t) and the total resident population (Pop) in the vicinity of the new campus amount to 1,643 persons and 2,613 persons, respectively. The increase in the number of relocated faculty experiences a rapid ascent, followed by a sharp decline and a

subsequent slower decrease. The peak in the rise of relocated faculty occurs at a subsidy level of 60,000 Yuan/Person/Year, beyond which the rate of relocation diminishes with further increases in the subsidy.

From Figure 4, it is evident that the marginal utility of the subsidy diminishes significantly after surpassing 60,000 Yuan/Person/Year. Initially, the subsidy’s marginal utility rises as transport accessibility and faculty housing preferences remain constant while housing prices change minimally. The optimal stage for the subsidy, where the rate of faculty relocation is highest, occurs when the subsidy aligns effectively with other influencing factors. However, as the surge in relocated faculty contributes to an elevation in housing prices, altering the subsidy’s proportion to other elements, the marginal utility of living around the new campus decreases, initiating a decline in the increment of relocated faculty.

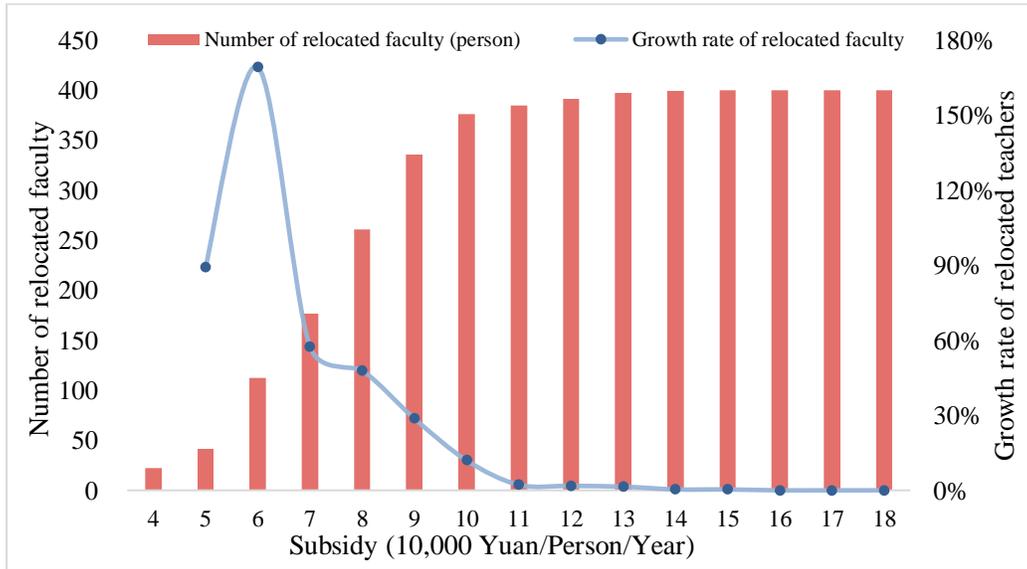


Figure 4. Variation in the number and growth rate of relocated faculty with increasing subsidy.

Figure 5 shows the variations in the overall production of the university with increasing subsidy levels. At subsidy levels of 40,000 Yuan/Person/Year and 100,000 Yuan/Person/Year, the total university production amounts to 7.2 million Yuan and 29.36 million Yuan, respectively. However, as subsidy surpasses 100,000 Yuan/Person/Year, the incremental growth in total production decelerates. Upon reaching the zenith at 30.84 million Yuan, where all faculty members have relocated, any further increase in subsidy ceases to impact the university's overall production.

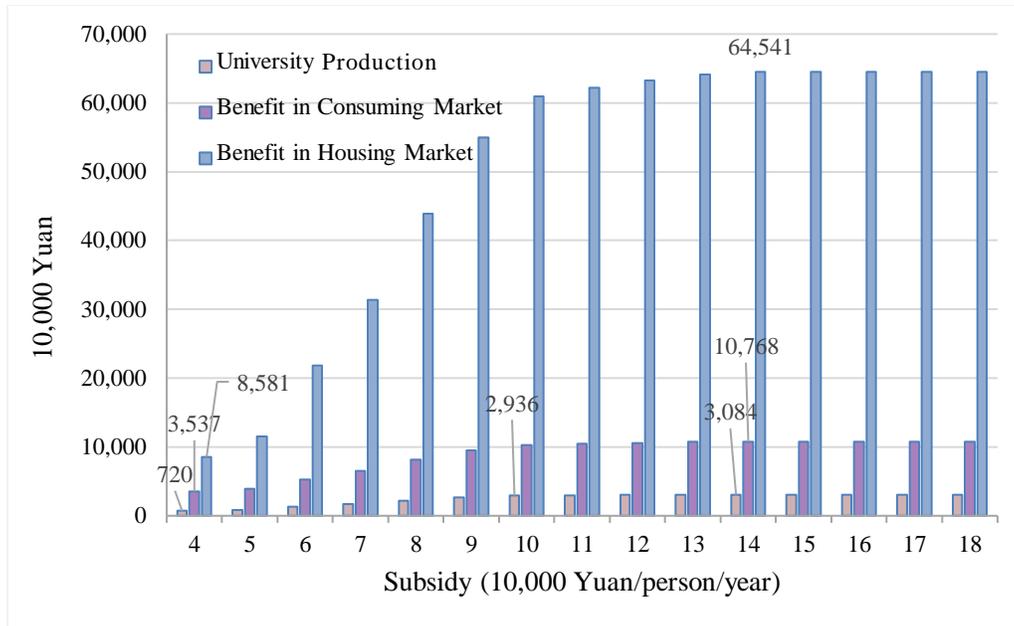


Figure 5. Variation in university production and in consumption and housing market benefits with increasing subsidy.

Figure 6 also illustrates the benefits to the consumption and housing markets resulting from faculty subsidies. The increase in subsidy, from 40,000 Yuan/Person/Year to 140,000 Yuan/Person/Year, leads to a rise in consumption market benefit from 35.37 million Yuan to 107.68 million Yuan. In the housing market, the benefit climbs from 85.81 million Yuan to 645.41 million Yuan. However, both consumption and housing market benefits plateau when all faculty members relocate to a residential zone near the new campus.

Figure 6 also shows the incremental benefits in the transportation sector. As subsidy increasing from 40,000 Yuan/Person/Year to 140,000 Yuan/Person/Year, the transportation sector benefit ascends from 0.36 million Yuan to 7.25 million Yuan.

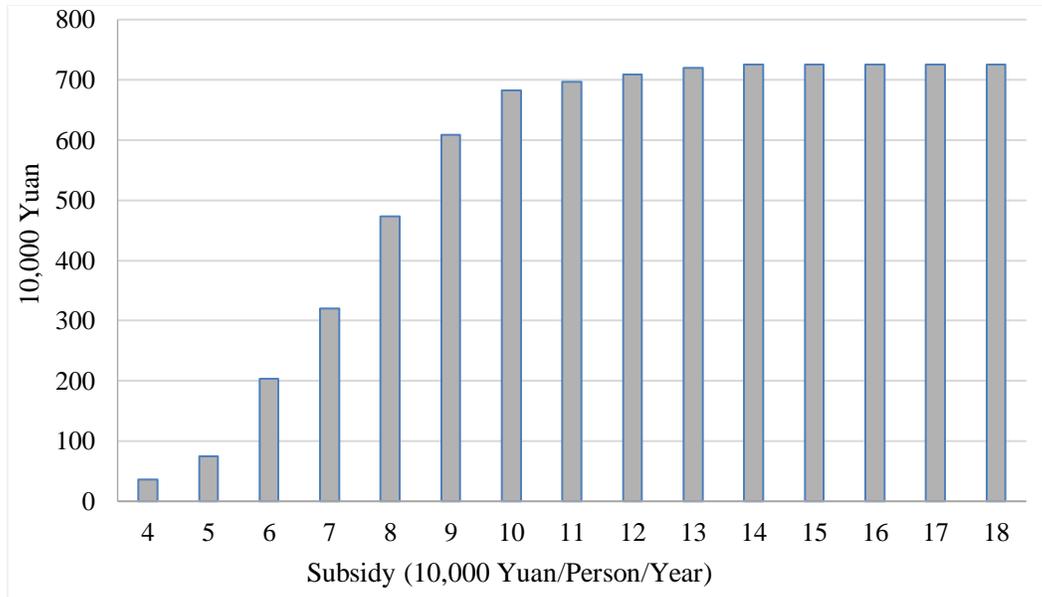


Figure 6. Variation in transportation sector benefit with increasing subsidy.

As depicted in Figure 7, the total benefit shows an initial rapid increase followed by a plateau as the subsidy level. When subsidy is below than 60,000 Yuan/Person/Year, the regional benefit is negative, at -21.42 million Yuan. At this point, 112 faculty opt to relocate to residential areas near the new campus. This suggests that the regional production level is below the minimum infrastructure investment, resulting in low benefits in the developing area. Upon reaching a subsidy of 140,000 Yuan/Person/Year, the regional benefit peaks at 499.41 million Yuan, with all 400 faculty choosing to relocate.

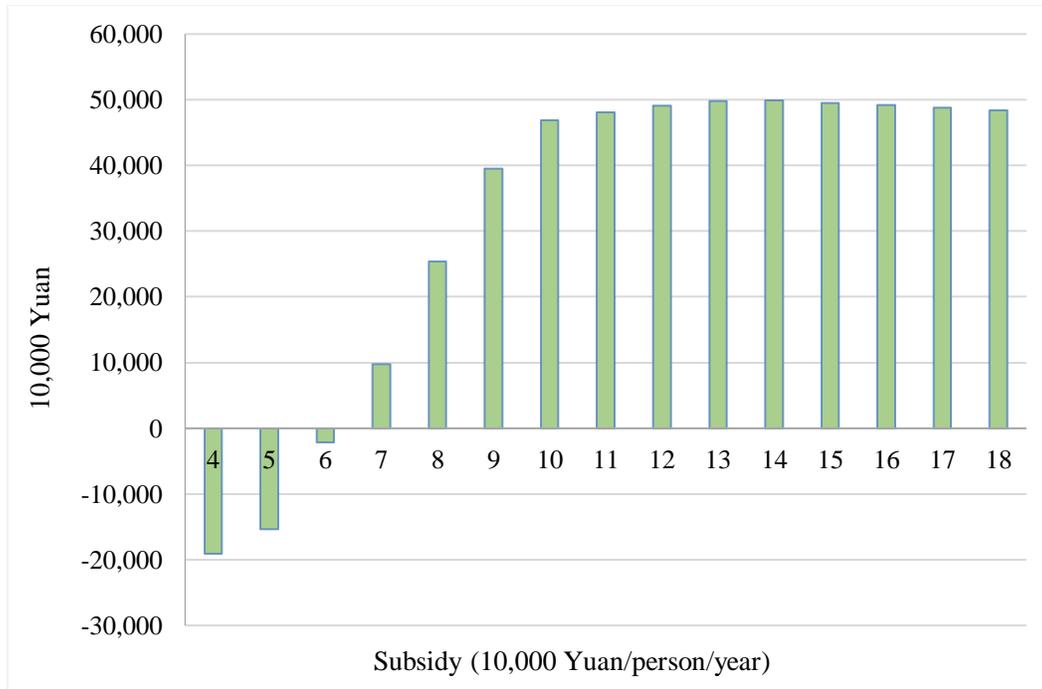


Figure 7. Variation in regional economic benefits with increasing subsidy.

The preceding discussion highlights that an increase in the relocation subsidy prompts a higher number of university faculty members to move closer to the new campus. The calculations demonstrate that, as the subsidy rises from a lower level, the willingness of faculty to relocate follows suit. Once the subsidy reaches a specific level, however, all faculty members opt to move closer to the new campus, and additional increases in subsidy do not lead to further faculty migration. Due to diminishing marginal benefits associated with incremental changes in the number of relocated faculty, the marginal benefits stabilize after a certain faculty threshold is reached and cease to increase.

7 Conclusion

This paper studies the impact of university suburbanization on urbanization in China, specifically focusing on the relocation of faculty members following a university's move to a remote suburb. The study considers various factors such as commute, shopping, medical care, leisure, education accessibility, housing price, faculty housing preferences, and relocation subsidy. A housing location model is constructed to analyze the influence of governmental subsidies on faculty relocation choices after the new campus opens.

The theoretical analysis is extended to build a regional benefit model that optimizes the subsidy level, aiming to maximize additional regional economic benefits in the areas of the university, transportation sector, and consumption and housing markets. Using the example of a Chinese university relocating to Meishan Island, the paper calibrates and conducts numerical analysis on the faculty relocation model, the education industry's production function, and the housing price model.

The results show that, as subsidy increases, the number of faculty willing to relocate also increases, leading to higher regional economic benefits. However, the rate of increase decreases with each incremental change in subsidy. When subsidy is below

50,000 Yuan/Person/Year, the number of relocating faculty is low, and additional regional economic benefits are negative. This is due to the fact that the subsidies cannot compensate the faculty for their loss in transport accessibility, and so the faculty members will continue to live in their original locations. The optimal subsidy level of 140,000 Yuan/Person/Year results in all faculty members choosing to relocate, maximizing economic benefits in the region. Additionally, the paper emphasizes the importance of the housing market, constituting 70% of the total additional regional economic benefits. This aligns with current practices in China, where city governments actively use land markets to promote suburbanization.

While the analysis is based on a specific case in Ningbo, the methodologies and models can be adapted for use in other Chinese cities to assist in formulating reasonable subsidy policies for suburbanization. It is essential to acknowledge that in areas with private land system, where the city government is not the landlord, the increased value in real estate resulting from government subsidies eventually becomes the landlord's profit. Therefore, incorporating the calculation of the return on land development into the model is crucial to prevent the loss of government benefits. This practice ensures a more accurate and comprehensive evaluation of the impact of subsidy policies in diverse urban contexts.

It's noted that the static production model used in the calculations here does not consider the input-output dynamics of new government investments such as in infrastructure, retail, healthcare, education, and transportation. Future studies could explore dynamic models, considering the evolving equilibrium between investment and transportation accessibility, providing a more realistic understanding of the suburbanization process.

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Author contribution

Zhongzhen Yang: Methodology and writing. Jiong Li: Formal analysis, review, and editing. Wenyuan Zhou: Data curation and calculation. Feng Lian: Conceptualization and formal analysis.

Appendices

Appendices available as a supplemental file at <https://doi.org/10.5198/jtlu.2024.2341>.

References

- Allison, J., & Eversole, R. (2008). A new direction for regional university campuses: Catalyzing innovation in place. *Innovation: The European Journal of Social Science Research*, 21(2), 95–109.
- Bauer, T. K., Braun, S. T., & Kvasnicka, M. (2017). Nuclear power plant closures and local housing values: Evidence from Fukushima and the German housing market. *Journal of Urban Economics*, 99, 94–106.
- Ben-Akiva, M. E., Choi, S., Park, C., & Park, J. (2014). A spatial-temporal analysis of population and employment growth for Southern California. *The Annals of Regional Science*, 52(1), 19–40.
- Bhat, C., Handy, S., Kockelman K., Mahmassani, H., Gopal, A., Srour, I., & Weston, L. (2002). *Development of an urban accessibility index: Formulations, aggregation, and application*. Austin, TX: Center for Transportation Research, University of Texas.
- Burns, L. D., & Golob, T. F. (1976). The role of accessibility in basic transportation choice behavior. *Transportation*, 5, 175–198
- Church, R. L., & Marston, J. R. (2003). Measuring accessibility for people with a disability. *Geographical Analysis*, 35(1), 83–96.
- Dalvi, M. Q., & Martin, K. M. (1976). The measurement of accessibility: Some preliminary results. *Transportation*, 5(1), 17– 42.
- Denison, E. F. (1962). Sources of economic growth in the United States and the alternatives before us. *The Journal of Finance*, 17(4),704.
- Elldér, E. (2014). Residential location and daily travel distances: The influence of trip purpose. *Journal of Transport Geography*, 34, 121–130.
- Felsenstein, D. (1996). The university in the metropolitan area: Impacts and public policy implications. *Urban Studies*, 33, 1568–1580.
- Goldner, W. (1971). The Lowry model heritage. *Journal of the American Institute of Planners*, 37(2), 100–110.
- Goldstein, H., & Drucker, J. (2006). The economic development impacts of universities on regions: Do size and distance matter? *Economic Development Quarterly*, 20(1), 22–43.
- Grengs, J. (2010). Job accessibility and the modal mismatch in Detroit. *Journal of Transport Geography*, 18(1), 42– 54.
- Guiliano, G., & Narayan, D. (2005). *A comparison of work and non-work travel: the US and Great Britain* (pp. 111–129). London: Spon Press.
- Hamidi, S., & Ewing, R. (2014). A longitudinal study of changes in urban sprawl between 2000 and 2010 in the United States. *Landscape and Urban Planning*, 128, 72–82.
- Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners*, 25(2), 73– 76.
- Heider, B., & Siedentop, S. (2020). Employment suburbanization in the 21st century: A comparison of German and US city regions. *Cities*, 104, 102802.
- Ingram, D. R. (1971). The concept of accessibility: A search for an operational form. *Regional Studies*, 5(2), 101–107.
- Karou , S., & Hull, A. (2014). Accessibility modelling: Predicting the impact of planned transport infrastructure on accessibility patterns in Edinburgh, UK. *Journal of Transport Geography*, 35, 1– 11.
- Lakshmanan, T. R., Nijkamp, P., Rietveld, P., & Verhoef, E. T. (2001). Benefits and costs of transport. *Papers in Regional Science*, 80(2), 139–164.

- Li, Z., Li, X., & Wang L. (2014). Speculative urbanism and the making of university towns in China: A case of Guangzhou University Town. *Habitat International*, 44, 422–431.
- Lowry, I. S. (1964). *A model of metropolis*. Santa Monica, CA: Rand Corp.
- Lu, H. P., Wang, J. F., & Zhang, Y. B. (2009). Model and application of transport accessibility in urban transport planning. *Journal of Tsinghua University (Natural Science Edition)*, 6, 781–785.
- Lucas, K., Van Wee, B., & Maat, K. (2016). A method to evaluate equitable accessibility: Combining ethical theories and accessibility-based approaches. *Transportation*, 43(3), 473–490.
- Luo, J. Y. (2008). The radiation effect of university town and the rise of educational real estate. *Consumption Tribune*, 16, 161.
- Marwal, A., & Silva, E. (2022). Literature review of accessibility measures and models used in land use and transportation planning in last 5 years. *Journal of Geographical Sciences*, 32, 560–584.
- Osman T., Shaw D., & Kenawy, E. (2018). An integrated land use change model to simulate and predict the future of greater Cairo metropolitan region. *Journal of Land Use Science*, 13(6), 565–584.
- Ouředníček, M., (2007). Differential suburban development in the Prague urban region. *Geografiska Annaler: Series B, Human Geography*, 89(2), 111–126.
- Páez, A., Scott, D. M., & Morency, C. (2012). Measuring accessibility: Positive and normative implementations of various accessibility indicators. *Journal of Transport Geography*, 25, 141–153.
- Rahel, N., & Christian, S. (2016). Beyond the urban–suburban divide: Urbanization and the production of the urban in Zurich north. *International Journal of Urban and Regional Research*, 40(3), 679–701.
- Reyes, M., Páez, A., & Morency, C. (2014). Walking accessibility to urban parks by children: A case study of Montreal. *Landscape and Urban Planning*, 125, 38–47.
- Rossi, F., & Goglio, V. (2020). Satellite university campuses and economic development in peripheral regions. *Studies in Higher Education*, 45(1), 34–54.
- Ruoppila, S., & Zhao, F. (2017). The role of universities in developing China’s university towns: The case of Songjiang university town in Shanghai. *Cities*, 69, 56–63.
- Schaldach, R., & Alcamo, J. (2007). Simulating the effects of urbanization, afforestation and cropland abandonment on a regional carbon balance: A case study for Central Germany. *Regional Environmental Change*, 7(3), 137–148.
- Sharma, G., & Patil, G. R. (2022). Spatial and social inequities for educational services accessibility—A case study for schools in Greater Mumbai. *Cities*, 122, 103543.
- Shen J. (2022). Universities as financing vehicles of suburbanization: The development of university towns in Shanghai. *Land Use Policy*, 112, 104679.
- Shi, X. L. (2006). Summary of depreciation of fixed assets in highway management enterprises. *Finance & Accounting for Communications*, 9, 44–45.
- Wang, D., Gong, Z. G., & Yang, Z. Z. (2018). Design of industrial clusters and optimization of land use in an airport economic zone. *Land Use Policy*, 77, 288–297.
- Wu, Z. M. (2008). Study on the suburban universities’ impetus to the suburban development: A case study of Chengdu suburbia. *Journal of Chengdu University*, 4, 53–58.
- Xia, Y. F. (2012). Function of college suburbanization in suburb urbanization: A case study of Xindu district of Chengdu city in China. *Journal of Landscape Research*, 5, 23–26 & 30.
- Yang, Z. Z., Zhu, X. C., & Moodie, D. (2015). Optimization of land use in a new urban district. *Journal of Urban Planning and Development*, 14(2), 05014010-1.

- Yi, D. L. (2021). Accessibility analysis of distance education resources based on multiple constraint model. *The International Journal of Electrical Engineering & Education*, 60(1), 002072092092098503.
- Yu, Q. L. (1985). Denison economic growth factor analysis. *Foreign Economics & Management*, 6, 33–36.
- Zheng, L., Van Wee, B., & Oeser, M. (2019). Combining accessibilities for different activity types. *Journal of Transport and Land Use*, 12(1), 853–872.
- Zhuge, C., Shao, C., Gao J., Dong, C., & Zhang, H. (2016). Agent-based joint model of residential location choice and real estate price for land use and transport model. *Computers, Environment & Urban Systems*, 57, 93–105.