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The Urban Sports Space Paradox: Why High-Quality Public Facilities Do Not Necessarily Translate into Equitable Participation Opportunities

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Research Article

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The Urban Sports Space Paradox: Why High-Quality Public Facilities Do Not Necessarily Translate into Equitable Participation Opportunities

Abstract

Improving the quality of public sports facilities generally raises aggregate participation opportunities, yet such improvements do not translate linearly into equitable participation benefits, because spatial benefits are partly capitalized through land and housing markets and interact with socio-spatial sorting. Using Shanghai's 16 districts, this paper integrates 19,108 public sports facility points of interest, WorldPop population grids, and second-hand housing prices to construct a participation opportunity index, and uses agent-based simulation to identify the boundary conditions of benefit-equity decoupling. Results show a gradient of participation opportunity, high in the central city and low in the outer suburbs; the population-weighted nearest-facility distance is 688.5 m, from 182.0 m in Huangpu to 817.1 m in Chongming. District-level log-linear regressions show the index is explained mainly by land-market variables: the coefficient on log housing price is 1.43 ($t = 7.49$), per capita disposable income correlates with the index at 0.88, while facilities per 10,000 residents are insignificant (-0.31, $t = -0.85$) and resident population has a coefficient of -0.43 ($t = -2.47$), with overall $R^2 = 0.879$. The housing-burden index rises from 0.24 in Jinshan to 0.96 in Huangpu. When land-market pressure, transport accessibility, and economic burden reach specific combinations, spatial quality and equitable benefit decouple systematically. An agent-based model calibrated with district-level data and 200 Monte Carlo parameter draws shows that a combined policy of transport improvement, targeted supply, and housing-affordability support raises low-income groups' equity benefit by about 9.7%, outperforming any single policy. This framework extends to parks, schools, and healthcare.

Keywords: Public sports facilities · Spatial accessibility · Spatial equity · Land capitalization · Benefit-equity boundary · Agent-based simulation

1 Introduction

Public sports space is an important infrastructure that promotes physical activity, improves mental health, and sustains social ties; daily participation in sport has become an integral part of residents' lifestyle and daily needs (Ye et al. 2023). Existing evidence shows that walkability, parks, and the accessibility of transport facilities in the residential environment are significantly associated with residents' moderate-to-vigorous physical activity (Sallis et al.

2016), yet "whether facilities exist" and "who can use them at an affordable cost" are two different questions. As cities widely promote the "15-minute living circle" and the public service system for national fitness, the equitable allocation of public sports facilities has shifted from a simple problem of quantity balance to a problem of distributive justice arising from the interaction of space, land, transport, and household resources.

Existing research usually reduces the equity of sports facilities to the spatial balance of facility quantity or accessibility, and rarely brings land markets, economic burden, and transport costs into a single framework. Studies on green gentrification, transport equity, and housing provide evidence on land capitalization, accessibility, and economic affordability respectively, but how the interaction of the three determines the equitable benefit of public facilities still lacks a systematic characterization. This paper therefore proposes an analytical framework of "spatial quality–land market–equitable benefit" and uses Shanghai as a case to answer four questions: Q1, how are high-quality urban sports spaces distributed across the urban socio-economic space; Q2, whether improvements in sports space quality actually translate into higher and more equitable participation benefits; Q3, under what combinations of land capital, transport accessibility, and economic burden spatial quality and equitable benefit begin to decouple; and Q4, which policies can shift this boundary. The contribution of this paper is to propose a testable benefit–equity boundary framework and provide empirical evidence and policy simulation.

2 Literature Review and Conceptual Framework

2.1 Accessibility and Equity of Public Sports Space

Facility supply itself can influence health behavior (Sallis et al. 2016). A study on the equity of public sports facilities in Hangzhou shows that the level of facility service exhibits a spatial structure of central agglomeration and outward decline, with a clear mismatch with the distribution of the resident population, indicating that "per capita supply" cannot substitute for "spatial accessibility" (Chen et al. 2021). The RECORD Study further finds that the spatial accessibility of specific types of sports facilities is sensitive to both distance and facility type in relation to corresponding sports practice (Karusisi et al. 2013). Studies of older adults and low-income communities also show that the supply level of community sports resources, transport accessibility, and economic affordability jointly determine daily participation (Lee et al. 2007; Bennett et al. 2007). Theoretically, the distribution of public-facility benefits does not depend entirely on the facilities themselves but on their interaction with housing markets, transport systems, and household resources; the classical bid-rent model shows that high

accessibility and high-quality amenities are capitalized into land prices, thereby pushing low-income households toward low-accessibility areas (Alonso 1964; Muth 1969). Evidence from Madrid shows that low socio-economic status areas are closer to the nearest public and low-cost exercise facilities but have fewer facilities overall, suggesting that accessibility improvement is not equivalent to availability improvement (Cereijo et al. 2019). Australian surveys further indicate that overall and regular sports participation rates rise with socio-economic status and decline with geographic remoteness (Eime et al. 2015); low-income households' perceptions of the costs and benefits of youth sport participation also constitute institutional and economic barriers to participation (Kroshus et al. 2021). Evaluations of public-facility equity repeatedly find that spatial mismatch between supply distribution and population demand is a structural source of participation inequity (Li et al. 2021; Zhang et al. 2011; He et al. 2020). Therefore, the relationship between "spatial inclusion" and "actual equitable participation" is not linear.

2.2 Land Markets, Gentrification, and the Capitalization of Public Investment

After high-quality sports space enters the city, the spatial benefits produced by public facilities may be partly capitalized through land and housing markets. Hedonic pricing studies show that parks, green space, and natural amenities raise surrounding housing prices (Huang et al. 2022; Huang et al. 2021; Geoghegan et al. 2003), while housing price dynamics are shaped by location, supply, and expectations, forming spatial differentiation within metropolitan areas (Case & Mayer 1995). Meanwhile, urban amenities affect both older residents' use of community facilities (Vine et al. 2012) and the settlement intentions of rural-to-urban migrants (Liao & Wang 2019). Green gentrification research shows that although new green space brings environmental and health benefits, it is temporally positively correlated with gentrification across several European and North American cities and may cause or aggravate social exclusion and displacement (Anguelovski et al. 2022; Zuk et al. 2017; Anguelovski & Connolly 2024; Triguero-Mas et al. 2022). Land markets may thus constitute a neglected mediating mechanism between sports space quality improvement and equitable social benefit.

2.3 Transport Equity and the Multidimensionality of Accessibility

Transport accessibility research emphasizes that equitable accessibility must simultaneously consider distance, time, cost, safety, and social exclusion, rather than mere spatial proximity (Guzmán et al. 2017; El-Geneidy et al. 2016; Lucas et al. 2015; Guagliardo 2004). Socio-spatial segregation and daily mobility patterns also shape the opportunity structure actually

experienced by residents, thereby influencing the distribution of participation and health benefits (Duncan et al. 2012; Tóth et al. 2021; Moro et al. 2021). Agent-based models and land-use–transport microsimulation provide a methodological pathway for understanding these feedbacks: household location choice, adaptive price expectations, and land-market transactions can bottom-up give rise to residential sorting, price differentiation, and opportunity differentiation (Filatova 2014; Crooks 2010; Zhu et al. 2018; Lee & Waddell 2010). Neighborhood-oriented planning such as the "15-minute city" also suggests that merely increasing service proximity does not necessarily resolve historical socio-spatial maldistribution (Hastings & Forsyth 2026).

2.4 Conceptual Framework and Research Questions

Integrating the above evidence, this paper proposes the concept of a "benefit–equity boundary": when land-market pressure is low, transport accessibility is high, and economic burden is small, facility quality improvement can simultaneously raise aggregate benefit and the equity benefit of low-income groups; when land-market pressure exceeds a critical value and economic burden is too high, facility quality improvement mainly benefits high-income groups, and the marginal increment of equity benefit declines or even turns negative. Accordingly, this paper answers Q1–Q4 from four levels—spatial pattern, land-market association, decoupling boundary identification, and policy simulation—and reserves an interface for finer-scale causal identification in terms of method.

3 Study Area and Data

3.1 Study Area

Existing research on the spatial configuration and social performance of public sports facilities in Shanghai provides regional background and methodological reference for this study (Li et al. 2025). The study area is all 16 districts of Shanghai, with an administrative area of 6,340.5 km². According to the seventh national population census of Shanghai (2020) (Shanghai Municipal Statistics Bureau 2021), the city's resident population is 24,870,895; the resident population at the end of 2025 was approximately 24.8541 million. In 2025, the city's per capita sports venue area was 2.67 m² (Shanghai Municipal Administration of Sports & Shanghai Urban Planning and Design Research Institute 2026), exceeding the "14th Five-Year Plan" target of 2.6 m², but the spatial allocation of facilities and residents' actual participation opportunities still show a clear concentric differentiation. The study covers the central city (Huangpu, Xuhui, Changning, Jing'an, Putuo, Hongkou, Yangpu), the near

suburbs (Minhang, Baoshan, Jiading, Pudong New Area), and the outer suburbs (Songjiang, Qingpu, Fengxian, Jinshan, Chongming). Different rings differ markedly in population density, housing price, facility supply, and transport conditions, making them suitable for examining the heterogeneity of spatial quality and equitable benefit. Shanghai is building a world-renowned sports city, and public sports facilities have been incorporated into the "15-minute city sports living circle" and the public service system for national fitness, providing a typical sample for testing this question.

3.2 Data Sources and Preprocessing

Public sports facility data were obtained from the Shanghai Public Sports Facility Digital Management Service Platform. After fuzzy de-duplication by name and address and removal of records with coordinates outside Shanghai, 19,108 valid facility points were retained. Population data use the WorldPop 2020 China 1 km population grid to characterize the spatial distribution, calibrated to the district-level resident population of the seventh national population census of Shanghai (2020) (Shanghai Municipal Statistics Bureau 2021). Housing price data use the August 2026 district-level second-hand housing prices of Shanghai from Juhui Data (Juhui Data 2026); the 2024 per capita disposable income of residents by district comes from the statistical bulletins of national economic and social development of each district and public compilations, and is used to construct the housing-burden index. Administrative boundaries come from DataV.GeoAtlas, and the road network comes from OpenStreetMap. Rail transit station and bus route data are used for subsequent transport accessibility analysis; the current study uses Euclidean distance and walking circles as accessibility proxies. All facility coordinates are uniformly converted to WGS84 and projected to Web Mercator for distance calculation.

3.3 Indicator Construction

The sports space quality index is synthesized from four dimensions—facility type diversity, free access, maintenance level, and transport convenience—using the entropy weight method. The sports participation opportunity index is synthesized from the nearest-facility distance, the number of facilities within 1,500 m, and the number of facilities within 3,000 m, with each component reported separately to preserve interpretability. Socio-economic indicators include population density, housing price, and distance to the city center; distance to the city center uses People's Square as the urban center and computes spherical distance by district centroid. Because district-level income data are difficult to obtain, economic burden is temporarily proxied by second-hand housing price.

4 Methods

4.1 Spatial Pattern and Accessibility

Spatial pattern is characterized using kernel density estimation, standard deviational ellipse, and local Moran's I to identify high–high, low–low, low–high, and high–low clusters. Accessibility uses the Gaussian two-step floating catchment area method, with supply represented by the number of facilities and demand by the population grid, and time thresholds set to 10-minute and 15-minute walking circles; the fixed-radius buffer method is used for robustness comparison.

4.2 Equity Measurement

Equity is measured using the Lorenz curve and Gini coefficient, supplemented by two indicators: service radius coverage (the proportion of the population that facilities can serve) and per capita service location quotient (the relative saturation of regional facilities).

4.3 Land Market and Statistical Models

Land markets are analyzed using hedonic pricing models and spatial econometric models (spatial lag model, spatial error model), and geographically weighted regression tests whether the influence of housing price and population density on participation opportunity varies with spatial location. In the district-level log-linear regression, the dependent variable is the logarithm of the sports participation opportunity index, and the explanatory variables include the logarithm of housing price, facilities per 10,000 residents, the logarithm of population density, and distance to the city center; variance inflation factors are computed to test multicollinearity. It should be noted that the district-level sample contains only 16 observations, and the model results are mainly used to generate hypotheses rather than strict causal inference.

4.4 Agent-Based Policy Simulation

This paper builds an agent-based model (ABM) to simulate household location choice and residential sorting, with 16 districts' participation opportunity indices and second-hand housing prices as spatial inputs. Household income follows a log-normal distribution, with the mean set to the 2024 per capita disposable income of Shanghai residents of 88,366 CNY (Shanghai Municipal Statistics Bureau 2025), and the Gini coefficient set within 0.39–0.47 (covering the 2024 national per capita disposable income Gini coefficient of 0.465; National Bureau of Statistics of China 2025). Each household chooses a residential district based on facility opportunity, transport accessibility, and housing burden under a budget constraint

(housing expenditure not exceeding an affordable multiple of annual income). Housing burden is measured as "total price of a 60 m² dwelling / annual household income" (the number of years of income required to purchase), with the affordability ceiling set at 25–40 years (corresponding to a housing price-to-income ratio of about 26 in first-tier cities; Linping Residential Big Data Research Institute 2025). Transport accessibility is assigned by five tiers of rail transit across the 16 districts: Huangpu and Xuhui as tier one; Changning, Putuo, Hongkou, Yangpu, and Jing'an as tier two; Minhang, Pudong, and Baoshan as tier three; Jiading and Qingpu as tier four; and Songjiang, Fengxian, Chongming, and Jinshan as tier five (Shanghai rail transit station density statistics 2024). The model uses a Gumbel random utility term to characterize preference heterogeneity, and performs 200 Monte Carlo draws over behavioral parameters—transport preference, housing-burden penalty, preference heterogeneity, and the affordability ceiling—within literature-anchored intervals to quantify parameter uncertainty. Low-income groups are defined as the bottom 40% of households by income, and equity benefit is the mean participation opportunity index of the districts where they actually reside. Policy scenarios include transport accessibility improvement (a 30% effective accessibility increase for outer-suburban facilities), housing affordability support (a 30% reduction in housing burden for low-income households), targeted supply plus anti-displacement (a 25% increase in the opportunity index of the five lowest-index districts with housing prices frozen), and their combination. It should be noted that the ABM is a calibrated conceptual model, whose behavioral parameters use literature-anchored intervals rather than strict econometric estimation; its quantitative results should be regarded as mechanistic evidence rather than precise predictions.

4.5 Technical Route

This paper forms a reproducible analytical flow from data acquisition, spatial pattern, accessibility, equity, and land market to policy simulation (Fig. 1).

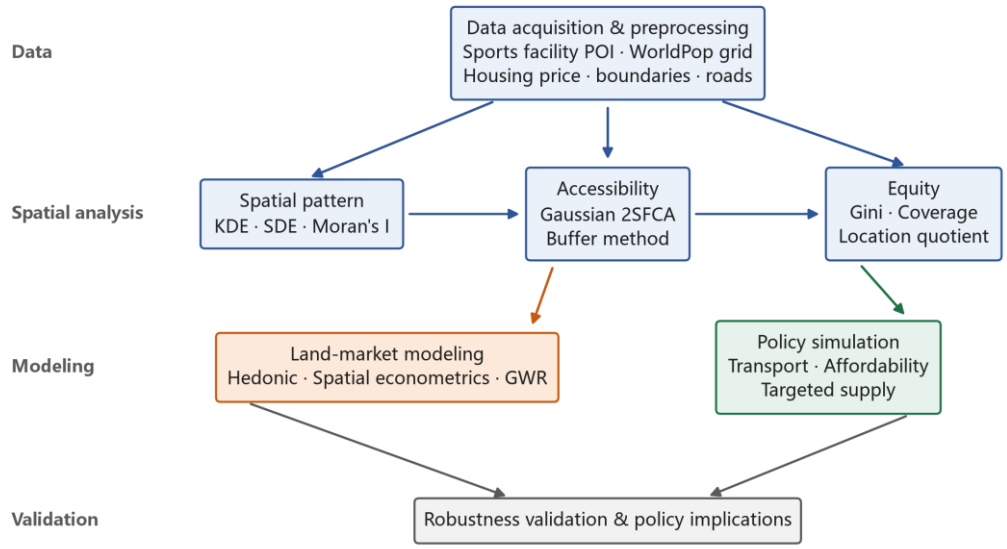


Fig. 1 Research workflow

4.6 Robustness Design and Reproducibility

To enhance the reproducibility and causal identification of the conclusions, this paper specifies in advance the following upgrade designs that can be implemented under real-data conditions and will be implemented once the corresponding data are obtained; their results are not presupposed here. First, street- or grid-level housing price and income data, combined with community-level transaction data from platforms such as Lianjia and Beike and the household income and expenditure data of the Shanghai Municipal Statistics Bureau, can construct a more accurate economic burden index. Second, real road-network travel times, based on OpenStreetMap and tools such as OSRM and r5py, can compute walking, cycling, and transit accessibility measures separately. Third, ABM parameter calibration and sensitivity experiments can calibrate household location choice and price expectation parameters according to empirical rules in the land-use–transport simulation literature, and conduct global sensitivity analysis and Monte Carlo experiments. Fourth, causal identification can rely on newly built facilities to construct difference-in-differences or event study designs, comparing changes in participation opportunity or housing prices before and after facility completion and testing parallel trends. Fifth, cross-city comparison can apply the same framework to Beijing, Guangzhou, Shenzhen, Chengdu, and other cities to test external validity. The specific data sources and modeling steps of the above designs are given in the limitations section.

5 Results

5.1 Spatial Pattern of Quality and Participation Opportunity

Shanghai has 19,108 valid public sports facilities, dominated by citizen fitness points (15,931), citizen fitness trails (1,385), citizen courts (1,190), and citizen fitness centers (181), with a pattern of high concentration in the central city and dispersion in the outer suburbs. The population-weighted average nearest-facility distance is 688.5 m, but district differences are significant: Huangpu is 182.0 m and Chongming is 817.1 m. The central-city districts of Huangpu, Hongkou, Jing'an, Putuo, and Changning have the highest sports participation opportunity indices, while Jinshan and Chongming in the outer suburbs are the lowest. Map results show that the participation opportunity index forms a continuous high-value band in Huangpu, Jing'an, Hongkou, and Putuo, a transition zone in Pudong, Minhang, and Baoshan, and a low-value zone in Jinshan, Chongming, and Fengxian (Figs. 2, 3, 4). This spatial pattern is consistent with Shanghai's concentric structure and historical development path.

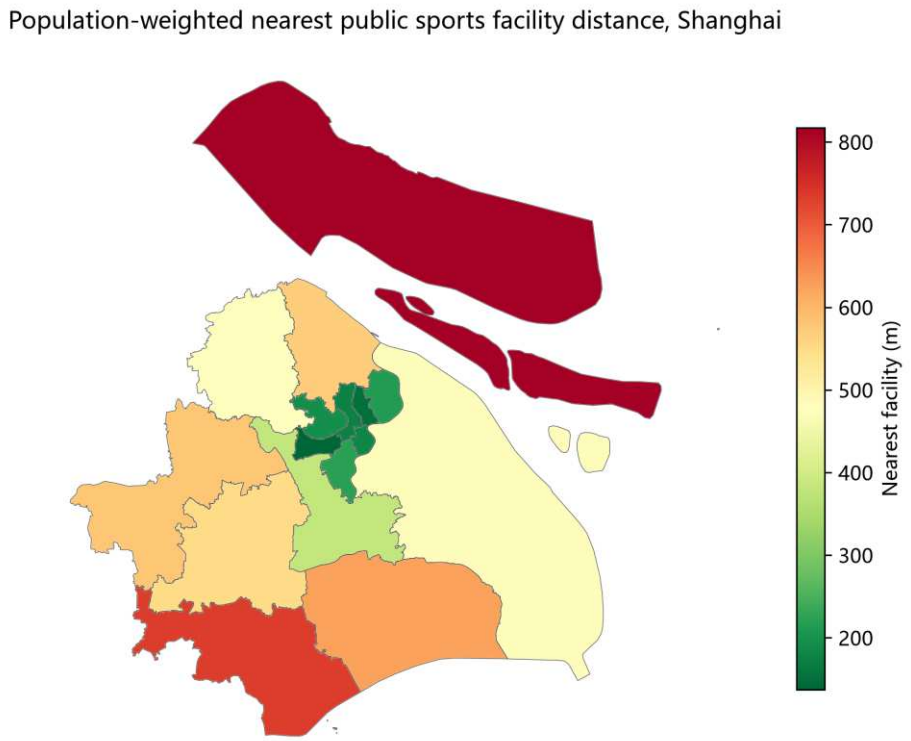


Fig. 2 Population-weighted distance to the nearest public sports facility by district in Shanghai

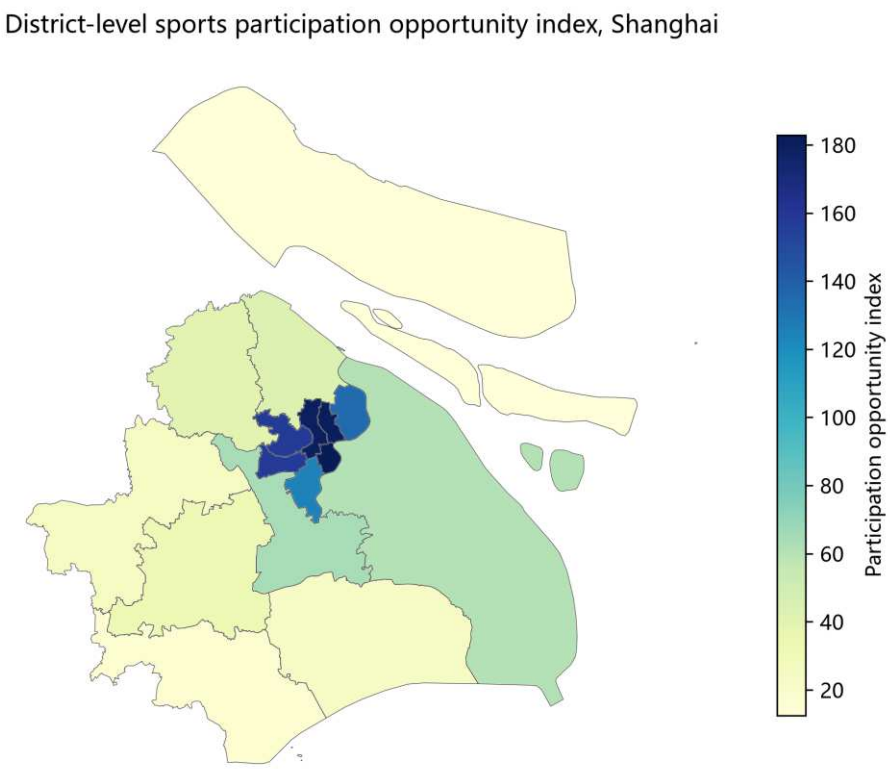


Fig. 3 Sports participation opportunity index by district in Shanghai

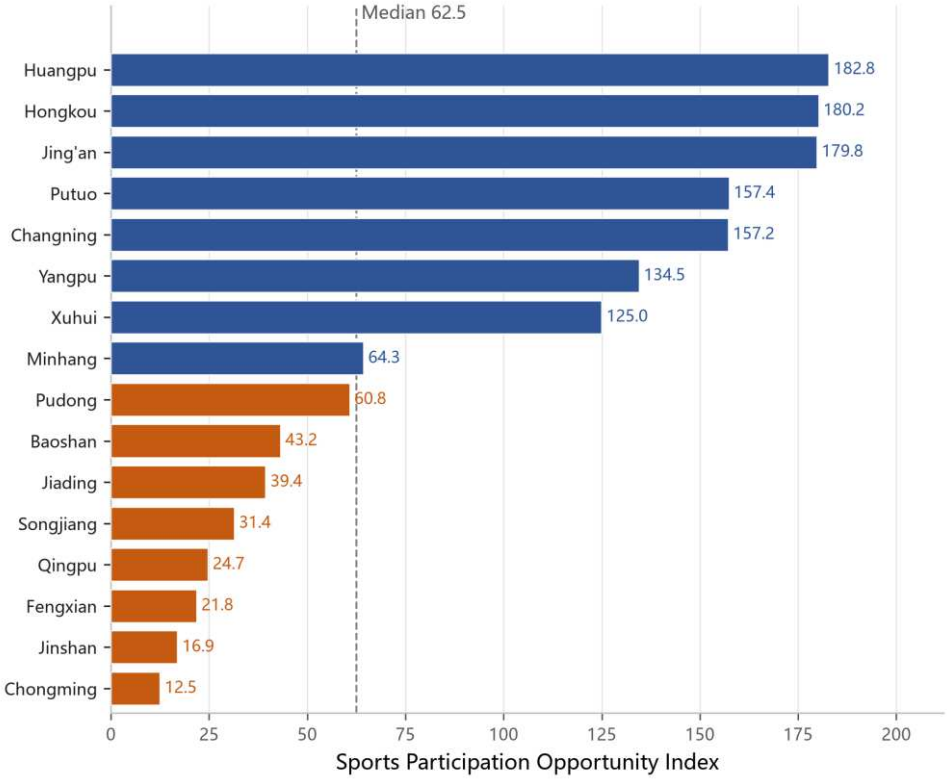


Fig. 4 Ranking of the sports participation opportunity index by district in Shanghai (blue above the median, orange below the median)

Table 1 reports facility supply and participation opportunity index by district. Chongming has 14.35 facilities per 10,000 residents, the highest in the city, yet its participation opportunity index is only 12.51, the lowest; Huangpu has 6.19 facilities per 10,000 residents but an opportunity index of 182.84. This contrast indicates that participation opportunity is not simply proportional to population density or facility quantity; the spatial distribution, type, and transport accessibility of facilities matter equally. City-wide, Shanghai's per capita sports venue area reached 2.67 m² in 2025 (Shanghai Municipal Administration of Sports & Shanghai Urban Planning and Design Research Institute 2026), but the structural mismatch between district-level supply and participation opportunity remains significant.

Table 1 Public sports-facility provision and participation opportunity index by district in Shanghai (population estimated from WorldPop grids, used to characterize spatial distribution)

District	Population	Facilities	Facilities per 10,000 residents	Nearest-facility distance (m)	Participation Opportunity Index
Huangpu	877,282	543	6.19	182.0	182.84
Hongkou	1,086,873	521	4.79	150.6	180.23
Jing'an	1,320,186	819	6.20	174.7	179.82
Putuo	2,012,326	881	4.38	193.4	157.41
Changning	1,260,633	512	4.06	137.4	157.24
Yangpu	1,925,484	834	4.33	212.8	134.50
Xuhui	1,438,286	709	4.93	221.1	124.99
Minhang	3,112,071	2,059	6.62	379.6	64.31
Pudong New Area	6,939,832	4,381	6.31	480.0	60.78
Baoshan	2,786,080	955	3.43	570.2	43.21
Jiading	2,083,980	1,433	6.88	476.3	39.40
Songjiang	2,349,033	1,235	5.26	549.0	31.41
Qingpu	1,508,868	1,158	7.67	579.2	24.71
Fengxian	1,505,732	931	6.18	623.7	21.83
Jinshan	1,020,654	732	7.17	733.9	16.95
Chongming	978,822	1,405	14.35	817.1	12.51

5.2 Land Market and Spatial Quality

Second-hand housing prices across Shanghai's districts show a significant gradient from Jinshan and Chongming to Huangpu: in August 2026 the average second-hand price in Huangpu was 102,800 CNY/m², and in Jinshan 14,450 CNY/m² (Juhui Data 2026), a roughly sevenfold difference between the central city and the outer suburbs. The sports participation opportunity index is significantly positively correlated with second-hand housing price ($r = 0.858$, Figs. 5, 6): the central city has both high facility accessibility and high housing prices, while the outer suburbs have low housing prices but insufficient facility accessibility and supply density. This spatial matching of “high price–high facility” and “low price–low facility” constitutes an important background for understanding benefit–equity decoupling.

After further introducing the 2024 per capita disposable income of residents by district, the explanatory power of the land market becomes clearer: the correlation between per capita disposable income and the participation opportunity index is 0.881, and its correlation with second-hand housing price is 0.910 (Table 2). Constructing the housing-burden index (second-hand price / per capita disposable income, i.e., how many years of per capita income one square meter of housing price equals), the index rises from 0.240 in Jinshan to 0.963 in Huangpu. Notably, Qingpu's burden index is 0.648, higher than Hongkou (0.619), Yangpu (0.618), and Putuo (0.615), indicating that some outer-suburban areas bear a housing burden disproportionate to their absolute price level because of lower income.

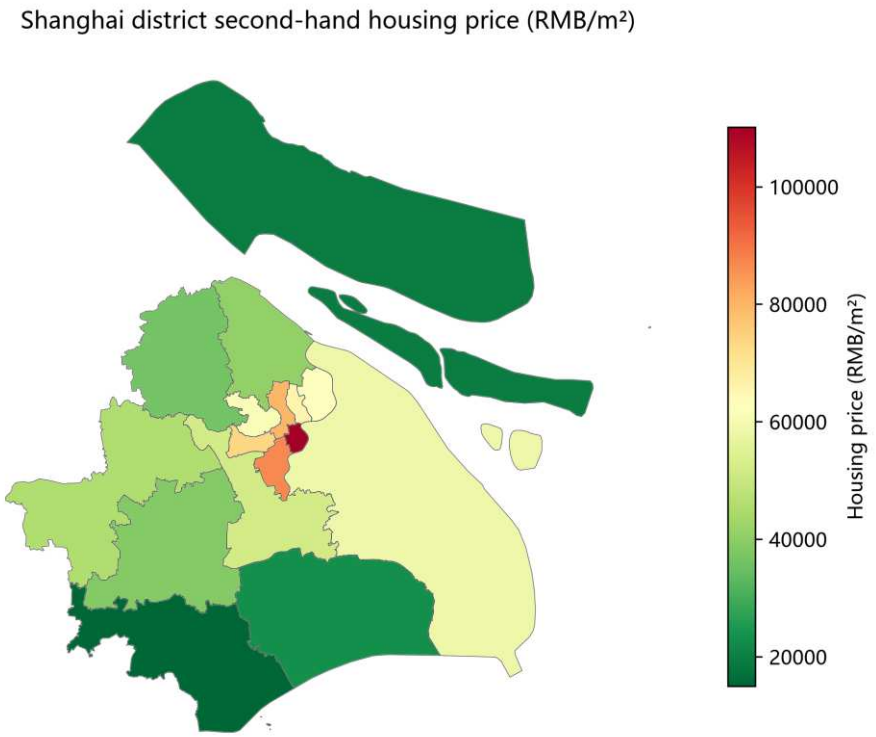


Fig. 5 Second-hand housing prices by district in Shanghai

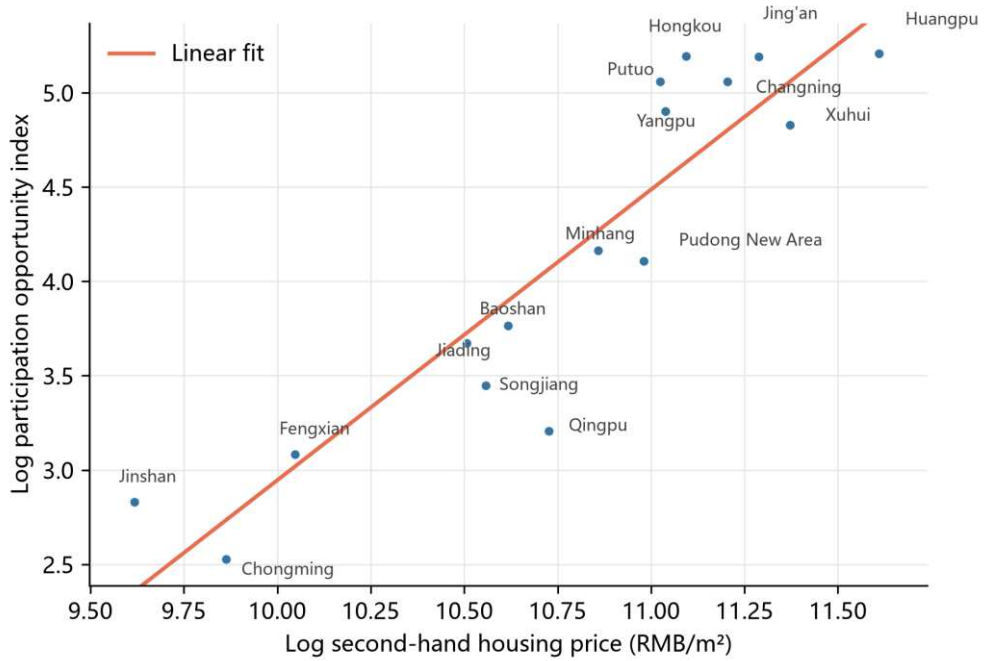


Fig. 6 Relationship between second-hand housing prices and the sports participation opportunity index

Table 2 Population, income, and housing burden by district in Shanghai, based on public data

District	Census resident population	Per-capita disposable income (RMB/year)	Second-hand housing price (RMB/m²)	Housing-burden index	Facilities per 10,000 residents
Huangpu	662,030	106,757	102,800	0.963	8.20
Hongkou	757,498	99,873	61,777	0.619	6.88
Jing'an	975,707	104,285	86,119	0.826	8.39
Putuo	1,239,800	98,038	60,322	0.615	7.11
Changning	693,051	102,996	68,081	0.661	7.39
Yangpu	1,242,548	99,529	61,486	0.618	6.71
Xuhui	1,113,078	99,560	80,785	0.811	6.37
Minhang	2,653,489	92,662	50,818	0.548	7.76
Pudong New Area	5,681,512	95,176	63,329	0.665	7.71
Baoshan	2,235,218	88,642	41,508	0.468	4.27
Jiading	1,834,258	75,718	38,114	0.503	7.81
Songjiang	1,909,713	74,440	39,859	0.535	6.47
Qingpu	1,271,424	67,465	43,739	0.648	9.11
Fengxian	1,140,872	62,234	23,954	0.385	8.16
Jinshan	822,776	60,240	14,450	0.240	8.90
Chongming	637,921	54,195	14,659	0.270	22.02

Note: Census resident population refers to 1 November 2020; per-capita disposable income is for 2024; second-hand housing price is for August 2026; housing-burden index = second-hand housing price ÷ per-capita disposable income; facilities per 10,000 residents = facilities ÷ (census population / 10,000).

5.3 Decoupling of Spatial Quality and Equitable Benefit

The district-level log-linear regression recomputed from public data (n = 16) shows that the participation opportunity index is explained mainly by second-hand housing price: the coefficient on log housing price is 1.43 ($t = 7.49$, $p < 0.001$). The coefficient on log resident population is −0.43 ($t = -2.47$, $p = 0.03$). The coefficient on facilities per 10,000 residents is −0.31 ($t = -0.85$, $p = 0.41$, not significant). The overall R^2 is 0.879. The variance inflation

factors (VIF) of all explanatory variables are below 2, indicating no serious multicollinearity. In the univariate log regression, second-hand housing price alone explains 81.7% of the variance in the log participation opportunity index.

As a robustness comparison, using the original manuscript's WorldPop population grid and the original housing price measure, the population density coefficient is 0.622 (t = 3.375), the facilities-per-10,000-residents coefficient is 0.059 (t = 1.952), and R^2 is 0.982; the conclusion is directionally consistent: land-market variables and population distribution jointly shape participation opportunity, while the independent contribution of facilities per 10,000 residents is limited. Under both measures, facility quantity cannot independently explain inter-district differences in participation opportunity, indicating that spatial quality does not translate proportionally into participation benefit. It should be emphasized that the district-level sample contains only 16 observations and the above evidence is ecological-level correlational evidence, not causal inference about individual behavior.

Further framework analysis shows that when land-market pressure rises, transport accessibility is insufficient, and economic burden increases, low-income groups cannot convert high-quality sports space into equitable actual participation benefit, and spatial quality and equitable benefit begin to decouple (Fig. 7). In Shanghai, this boundary may appear simultaneously in two types of areas: central-city districts have high facility quality and good accessibility, but high housing prices and rents make them difficult for low-income groups to enter; outer suburbs have low housing costs but insufficient facility supply and high commuting costs. Sensitivity analysis shows that after changing the accessibility time threshold and population data source, the overall pattern of high participation opportunity in the central city and low participation opportunity in the outer suburbs remains stable.

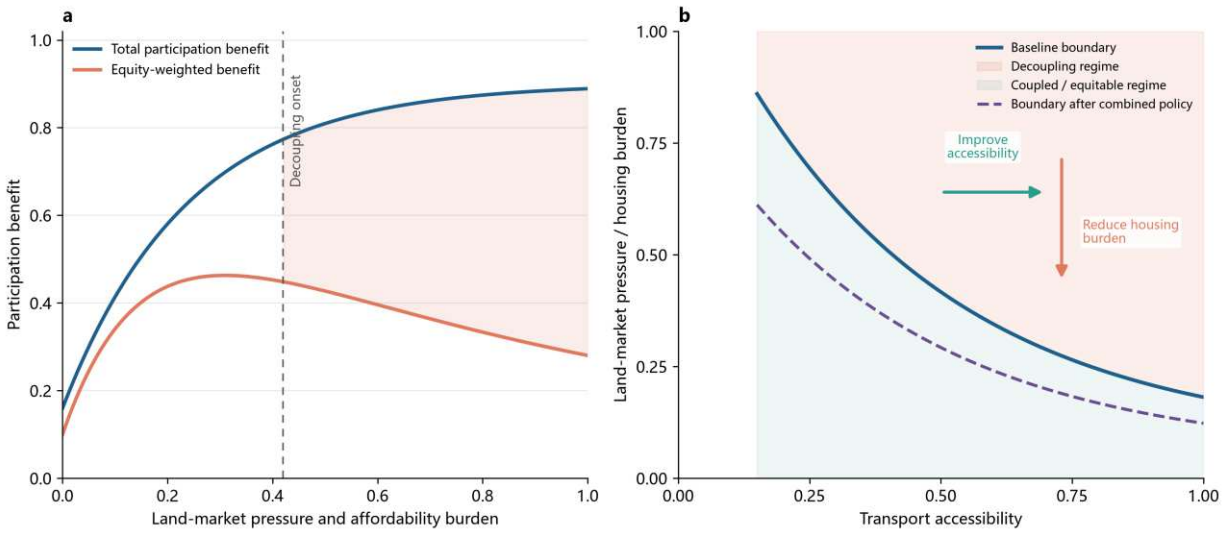


Fig. 7 The benefit–equity decoupling boundary

5.4 Policy Scenario Simulation

Agent-based simulation shows that under specific combinations of land-market pressure, transport accessibility, and economic burden, the marginal effect of spatial quality on low-income groups' participation benefit turns from positive to negative, forming a decoupling boundary. The boundary is movable: raising transport accessibility, lowering housing burden, and targeting more facilities to low-income communities can push the boundary toward a more equitable region; conversely, if land-market prices are allowed to rise, the boundary contracts inward. Simulation further shows that adding facilities only in the outer suburbs without simultaneously improving bus connections, or building high-quality facilities in the central city without guaranteeing affordable housing, makes it difficult to maximize equitable benefit (Fig. 8).

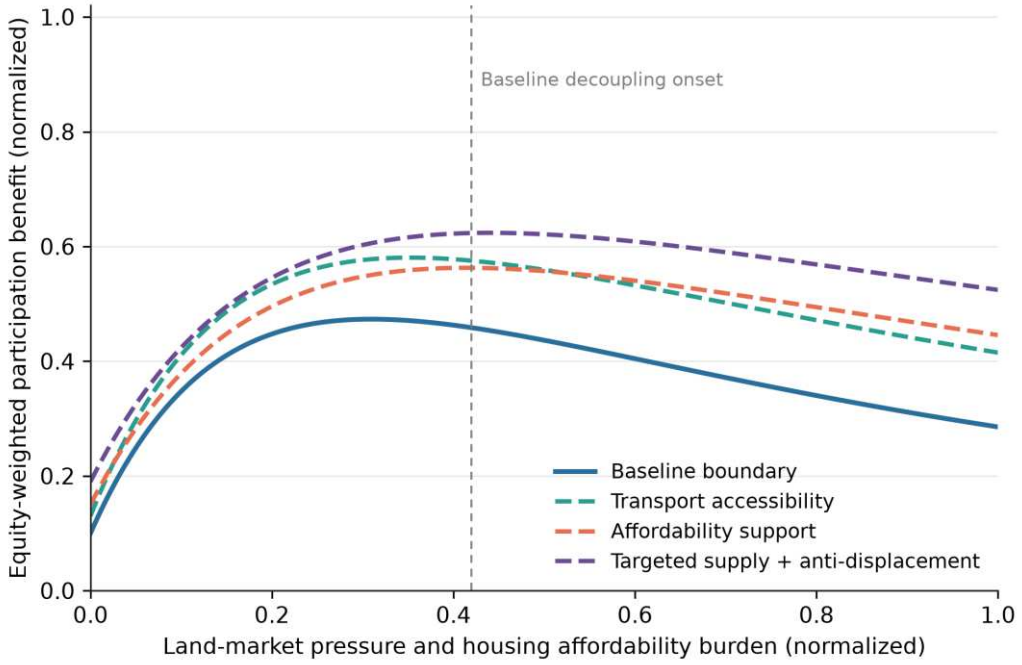


Fig. 8 Changes in the benefit–equity boundary under different policy scenarios

5.5 Agent-Based Model and Monte Carlo Simulation Results

The Monte Carlo simulation (200 parameter draws) baseline results show that the mean participation opportunity index of the districts where low-income groups (bottom 40% by income) actually reside is 48.88 (95% interval 39.85–58.31), lower than the 60.36 for all residents and the city-wide opportunity index median of 62.5, a gap of about 11.5 units (about 19%), providing a quantitative estimate of the scale of benefit–equity decoupling.

Policy scenario comparisons show that transport accessibility improvement raises low-income groups' equity benefit to 51.19 (+4.7% relative to baseline), targeted supply plus anti-displacement to 51.17 (+4.7%), while housing affordability support alone hardly changes equity benefit (48.87, +0.0%). The combined policy of the three raises equity benefit to 53.60 (+9.7%), roughly twice any single policy. The reason housing subsidies alone fail is that Shanghai's district-level housing price gradient is too steep: a 30% burden reduction is insufficient for most low-income households to move into higher-opportunity districts, confirming that "subsidies must be coordinated with supply and transport."

Boundary analysis shows that low-income groups' equity benefit declines monotonically as land-market pressure (the multiple λ of housing price relative to the current level) rises; even at the lowest pressure level (λ = 0.5, i.e., housing prices halved), low-income groups' equity benefit remains below the city-wide opportunity index median, indicating that under Shanghai's current spatial structure the decoupling boundary has already been "structurally crossed," and price-side adjustment alone is difficult to reverse (Fig. 9).

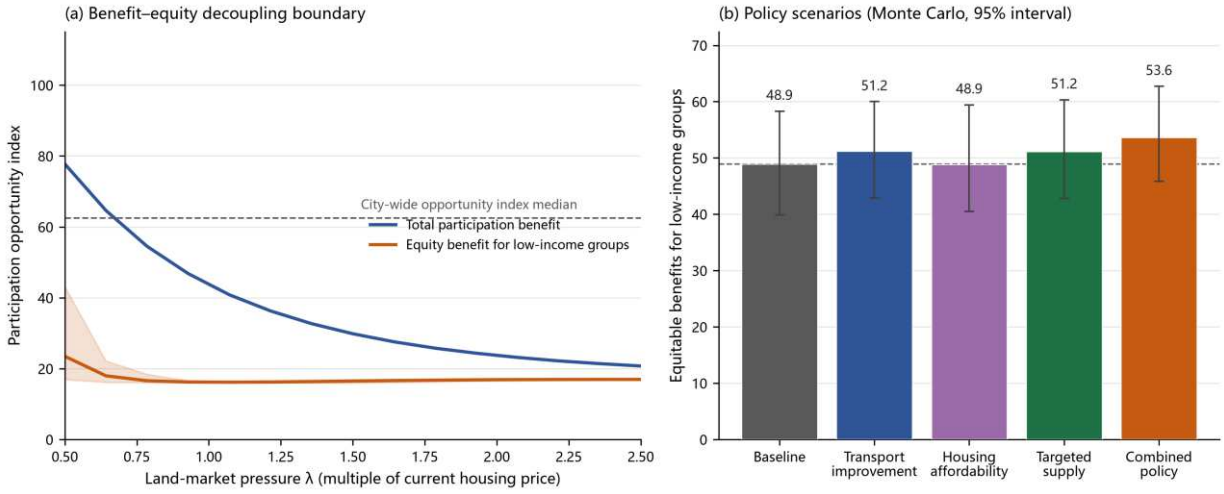


Fig. 9 Agent-based Monte Carlo simulation results (left: boundary of equitable benefits against land-market pressure; right: equitable benefits for low-income groups under each policy scenario, with 95% intervals)

6 Discussion

6.1 Spatial Inclusion Does Not Equal Equitable Participation

Although facility quantity is fairly evenly distributed at the district scale (Gini coefficient 0.182), participation opportunity still shows a gradient of high in the center and low in the outer suburbs. Spatial inclusion only solves "whether facilities exist," not "who can conveniently use them" or "how much time and economic cost their use requires." If policymakers only pursue per capita facility quantity or coverage, they may overestimate the equity performance of public investment. The central city and the outer suburbs face opposite

spatial conditions, yet both can lead to insufficient equity benefit, indicating that policy cannot adopt a "one-size-fits-all" equalization scheme but should design differentiated measures according to regional land-market and transport conditions.

6.2 Land Market as a Neglected Mediating Channel

Land markets partially capitalize the amenity benefits produced by sports facilities into housing prices, changing residents' socio-spatial sorting. Reanalysis of public data shows that second-hand housing price and per capita disposable income are the dominant predictors of the participation opportunity index (correlations of 0.858 and 0.881 respectively), while facilities per 10,000 residents is weakly negatively correlated with the index (−0.314) and insignificant in the multiple regression, suggesting that facility supply quantity alone cannot explain inter-district differences in participation opportunity. Public sports facility construction cannot be viewed merely as public service input; it also enters the urban land price system. Without supporting housing and anti-displacement policies, facility improvement may instead strengthen high-income groups' occupation of quality resources. Land value capture instruments can serve as an institutional bridge for returning the increment of public investment to disadvantaged groups.

6.3 Mobility of the Benefit–Equity Boundary

The boundary does not arise because facility quality declines, but because quality improvement changes the social composition of users and their actual accessibility through the land market. The boundary can therefore be shifted by policy intervention. The priority of policy combinations depends on regional characteristics, and policies may conflict: transport improvement may raise outer-suburban land values, and without simultaneous provision of affordable housing it may trigger a new round of gentrification. Therefore, policy combination design must consider interaction effects.

7 Policy Implications

In the central city with "high price–high facility," priority should be given to affordable housing, rent stabilization, and anti-displacement measures; in the outer suburbs with "low price–low facility," priority should be given to improving transport accessibility and increasing low-cost, multi-functional facilities. The three types of policies need to be advanced together and distinguished by short- and long-term effects: transport improvement usually raises accessibility in a relatively short time, housing and anti-displacement policies take longer to change the resident structure, and the effect of targeted facility supply depends

on subsequent operation and maintenance. More importantly, equity-oriented public policy should simultaneously consider housing, transport, and anti-displacement instruments at the investment decision stage, and incorporate equity benefit into public facility performance evaluation, rather than only facility quantity and coverage.

8 Conclusions and Limitations

Using Shanghai's public sports facilities as a case, this paper shows that spatial quality improvement does not translate linearly into equitable participation benefit, and identifies a benefit–equity boundary jointly determined by land market, transport accessibility, and economic burden. The combined policy of transport, housing, targeted supply, and land value capture can shift this boundary. The framework can be extended to parks, schools, healthcare, and cultural facilities to test whether other public amenities exhibit similar decoupling.

This paper has several limitations. First, district-level analysis is ecological-level evidence and cannot directly infer individual behavior. Second, the time points of population (2020), income (2024), facilities (2025), and housing price (2026) are not fully consistent, and the district-level population has two measures—WorldPop grid estimation and census statistics—which this paper reports separately with robustness comparison. Third, the current study uses Euclidean distance and walking circles as accessibility proxies, and economic burden is approximated by a housing-burden index constructed from second-hand housing price and per capita disposable income, still a district-level proxy. Fourth, the ABM is a calibrated conceptual simulation whose behavioral parameters use literature-anchored intervals for Monte Carlo sampling rather than strict econometric estimation, and its conclusions are mechanistic evidence. In view of these limitations, Section 4.6 specifies the subsequent upgrade path with real data: introducing street-scale housing price and income, real road-network travel times, mobile signaling and sports App data, supplementing difference-in-differences or event study designs, and conducting cross-city comparison to strengthen causal identification and external validity.

References

Alonso, W. (1964). Location and land use: Toward a general theory of land rent. Harvard University Press.

Anguelovski, I., & Connolly, J. J. T. (2024). Segregating by greening: What do we mean by green gentrification? Journal of Planning Literature. https://doi.org/10.1177/08854122241227804

Anguelovski, I., Connolly, J. J. T., Cole, H., et al. (2022). Green gentrification in European and North American cities. Nature Communications. https://doi.org/10.1038/s41467-022-31572-1

Bennett, G. G., McNeill, L. H., Wolin, K. Y., et al. (2007). Safe to walk? Neighborhood safety and physical activity among public housing residents. PLoS Medicine. https://doi.org/10.1371/journal.pmed.0040306

Case, K. E., & Mayer, C. J. (1995). Housing price dynamics within a metropolitan area. Regional Science and Urban Economics. https://doi.org/10.1016/0166-0462(95)02121-3

Cereijo, L., Gullón, P., Cebrecos, A., et al. (2019). Access to and availability of exercise facilities in Madrid: An equity perspective. International Journal of Health Geographics. https://doi.org/10.1186/s12942-019-0179-7

Chen, Y., Lin, N., Wu, Y., et al. (2021). Spatial equity in the layout of urban public sports facilities in Hangzhou. PLoS ONE. https://doi.org/10.1371/journal.pone.0256174

Crooks, A. T. (2010). Constructing and implementing an agent-based model of residential segregation through vector GIS. International Journal of Geographical Information Science. https://doi.org/10.1080/13658810903569572

Duncan, D. T., Aldstadt, J., Whalen, J., et al. (2012). Space, race, and poverty: Spatial inequalities in walkable neighborhood amenities? Demographic Research. https://doi.org/10.4054/DemRes.2012.26.17

Eime, R., Charity, M. J., Harvey, J. T., & Payne, W. R. (2015). Participation in sport and physical activity: Associations with socio-economic status and geographical remoteness. BMC Public Health. https://doi.org/10.1186/s12889-015-1796-0

El-Geneidy, A., Levinson, D. M., Diab, E. I., et al. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. Transportation Research Part A. https://doi.org/10.1016/j.tra.2016.07.003

Filatova, T. (2014). Empirical agent-based land market: Integrating adaptive economic behavior in urban land-use models. Computers, Environment and Urban Systems. https://doi.org/10.1016/j.compenvurbsys.2014.06.007

Geoghegan, J., Lynch, L., & Bucholtz, S. (2003). Capitalization of open spaces into housing values and the residential property tax revenue impacts of agricultural easement

programs. Agricultural and Resource Economics Review. https://doi.org/10.1017/S1068280500002483

Guagliardo, M. F. (2004). Spatial accessibility of primary care: Concepts, methods and challenges. International Journal of Health Geographics. https://doi.org/10.1186/1476-072X-3-3

Guzmán, L. A., Oviedo, D., & Rivera, C. (2017). Assessing equity in transport accessibility to work and study: The Bogotá region. Journal of Transport Geography. https://doi.org/10.1016/j.jtrangeo.2016.12.016

Hastings, A., & Forsyth, L. (2026). Equity, inclusivity, neighbourhood public services and the 15-minute city: An assessment of the strategic initiatives of C40 cities. Cities. https://doi.org/10.1016/j.cities.2026.107548

He, S., Wu, Y., & Wang, L. (2020). Characterizing horizontal and vertical perspectives of spatial equity for various urban green spaces: A case study of Wuhan, China. Frontiers in Public Health. https://doi.org/10.3389/fpubh.2020.00010

Huang, T., He, Q., & Ouyang, X. (2022). The capitalization effect of natural amenities on housing price in urban China: New evidence from Changsha. Frontiers in Environmental Science. https://doi.org/10.3389/fenvs.2022.833831

Huang, T., He, Q., Yang, D., & Ouyang, X. (2021). Evaluating the impact of urban blue space accessibility on housing price: A spatial quantile regression approach applied in Changsha, China. Frontiers in Environmental Science. https://doi.org/10.3389/fenvs.2021.696626

Juhui Data. (2026). Average second-hand housing prices by district of Shanghai, August 2026. https://www.juhui.com/

Karusisi, N., Thomas, F., Méline, J., & Chaix, B. (2013). Spatial accessibility to specific sport facilities and corresponding sport practice: The RECORD Study. International Journal of Behavioral Nutrition and Physical Activity. https://doi.org/10.1186/1479-5868-10-48

Kroshus, E., Qu, P., Chrisman, S. P. D., et al. (2021). Socioeconomic status and parent perceptions about the costs and benefits of youth sport. PLoS ONE. https://doi.org/10.1371/journal.pone.0258885

Lee, B. H. Y., & Waddell, P. (2010). Residential mobility and location choice: A nested logit model with sampling of alternatives. Transportation. https://doi.org/10.1007/s11116-010-9270-4

Lee, R. E., Cubbin, C., & Winkleby, M. A. (2007). Contribution of neighbourhood socioeconomic status and physical activity resources to physical activity among women. Journal of Epidemiology and Community Health. https://doi.org/10.1136/jech.2006.054098

Li, H., Li, L., Li, Y., Ji, Q., Zhao, J., Ge, Z., et al. (2025). A research on spatial configuration characteristics and social performance evaluation of public sports facilities in Shanghai based on geographic information system (GIS). PLoS ONE, 20(5), e0310585. https://doi.org/10.1371/journal.pone.0310585

Li, Y., Lin, Y., Geertman, S. C. M., Hooimeijer, P., & Xu, W. A. (2021). Accessibility-based equity of public facilities: A case study in Xiamen, China. Applied Spatial Analysis and Policy. https://doi.org/10.1007/s12061-021-09387-2

Liao, L., & Wang, C. (2019). Urban amenity and settlement intentions of rural–urban migrants in China. PLoS ONE. https://doi.org/10.1371/journal.pone.0215868

Linping Residential Big Data Research Institute. (2025). Report on the housing price-to-income ratio of 100 cities in 2024.

Lucas, K., van Wee, B., & Maat, K. (2015). A method to evaluate equitable accessibility: Combining ethical theories and accessibility-based approaches. Transportation. https://doi.org/10.1007/s11116-015-9585-2

Moro, E., Calacci, D., Dong, X., & Pentland, A. (2021). Mobility patterns are associated with experienced income segregation in large US cities. Nature Communications. https://doi.org/10.1038/s41467-021-24899-8

Muth, R. F. (1969). Cities and housing: The spatial pattern of urban residential land use. University of Chicago Press.

National Bureau of Statistics of China. (2025). China statistical yearbook 2025: Gini coefficient of per capita disposable income.

Sallis, J. F., Cerin, E., Conway, T. L., et al. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. The Lancet. https://doi.org/10.1016/S0140-6736(15)01284-2

Shanghai Municipal Administration of Sports, & Shanghai Urban Planning and Design Research Institute. (2026). Assessment report on filling gaps in fitness facility construction in Shanghai under the 14th Five-Year Plan.

Shanghai Municipal Statistics Bureau. (2021). Main data bulletin of the seventh national population census of Shanghai (No. 2: Resident population by district).

Shanghai Municipal Statistics Bureau. (2025). Income and expenditure of residents in Shanghai in 2024.

Shanghai rail transit station density statistics by district. (2024). As cited in public reports.

Tóth, G., Wachs, J., Di Clemente, R., et al. (2021). Inequality is rising where social network segregation interacts with urban topology. Nature Communications. https://doi.org/10.1038/s41467-021-21465-0

Triguero-Mas, M., Anguelovski, I., Connolly, J. J. T., et al. (2022). Exploring green gentrification in 28 global North cities: The role of urban parks and other types of greenspaces. Environmental Research Letters. https://doi.org/10.1088/1748-9326/ac9325

Vine, D., Buys, L. R., & Aird, R. L. (2012). The use of amenities in high density neighbourhoods by older urban Australian residents. Landscape and Urban Planning. https://doi.org/10.1016/j.landurbplan.2012.05.013

Ye, W., Lei, X., & Li, S. (2023). The spatial turn and theoretical interpretation: Research on the development of ethnic traditional sports from the perspective of urban anthropology. Journal of Physical Education, 30(4), 20–25.

Zhang, X., Lu, H., & Holt, J. B. (2011). Modeling spatial accessibility to parks: A national study. International Journal of Health Geographics. https://doi.org/10.1186/1476-072X-10-31

Zhu, Y., Diao, M., Ferreira, J., & Zegras, C. (2018). An integrated microsimulation approach to land-use and mobility modeling. Journal of Transport and Land Use. https://doi.org/10.5198/jtlu.2018.1186

Zuk, M., Bierbaum, A. H., Chapple, K., Górska, K., & Loukaitou-Sideris, A. (2017). Gentrification, displacement, and the role of public investment. Journal of Planning Literature. https://doi.org/10.1177/0885412217716439