ISSN: 1648-715X / eISSN: 1648-9179

INTERNATIONAL JOURNAL OF STRATEGIC PROPERTY MANAGEMENT

2026
Volume 30
Issue 3
Pages 243–258
https://doi.org/10.3846/ijspm.2026.27794

HOW DOES CHINA'S HOUSING AFFORDABILITY AFFECT URBAN INNOVATION?

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Article History:
- received 29 May 2025
- accepted 16 March 2026

Abstract. The primary objective of this paper is to examine the complex mechanisms governing the influence of housing supply-demand dynamics and affordability on urban innovation levels in China. Specifically, we dissect the interplay between housing affordability, human capital, and the intermediary pathways connecting them. Our empirical analysis reveals that an escalation in the housing supply-demand ratio inhibits urban innovation levels by traversing through the intermediary channels. Moreover, our investigation uncovers notable disparities in the chained intermediary effects between innovative and non-innovative pilot cities. In innovative pilot cities, an increase in the housing supply-demand ratio represses urban innovation levels, whereas, in non-innovative pilot cities, it augments them.

Keywords: housing affordability, human capital, chain intermediary effect, urban innovation, China.

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1. Introduction

Chinese cities have become hubs of population aggregation while simultaneously operating as functional clusters of innovation, technology, and culture. Innovation, as the driving force behind societal development, plays a crucial role in the rapid economic growth of cities. The escalating housing prices in China have emerged as a significant challenge to the concentration of high-tech populations in urban centers, consequently impacting urban innovation capabilities. For instance, statistics published by the *Zhuge Data Research Center* indicate that the house price-to-income ratio soared to 28.5 in first-tier cities and 12.3 in second-tier cities in 2023. Such inflated housing costs in Chinese urban areas impede the mobility of innovative talent and prevent urban innovation ecosystems from flourishing. To better address the challenges associated with this scenario, there is a requirement to generate meaningful insights into the correlation between the housing market and urban innovation capabilities. Furthermore, there is a need to delineate the intricate pathways that the housing market traverses to exert its influence on innovation capabilities.

Taking a broader perspective, cities worldwide are undergoing rapid metamorphoses and confronting a myriad of challenges. Previous research has found that housing prices have a profound influence on urban innovation levels through the intermediary conduit of human capital. For example, Lin et al. (2021) elucidated how housing costs directly impact talent's choices regarding employment and housing, thereby impacting innovation performance at the city level. Human capital levels, recognized as a fundamental determinant of urban innovation, are themselves influenced by housing affordability, which in turn shapes residential preferences. However, existing literature predominantly scrutinizes the correlation between housing prices and urban innovation and fails to engage in an exploration from the vantage point of housing supply and demand dynamics. Furthermore, there is also a gap in understanding of the extent to which housing markets impact urban innovation levels via a chain-like intermediary pathway that encompasses housing affordability and human capital levels. Therefore, this study aimed to better understand the mechanism through which the housing market exerts its influence on urban innovation, adopting novel perspectives of housing supply and demand relationships and housing affordability.

2. Literature review

The concept of "innovation" first made its debut in economic discourse in 1912 in American-Austrian economist Joseph Schumpeter's seminal work, "The Theory of Economic Development". Schumpeter defined innovation as the establishment of a new production function aimed at achieving a fresh amalgamation of production factors and conditions. This encompassed the introduction of novel products or enhancements in product quality, the adoption of innovative production methods, the exploration of untapped markets, the utilization of novel materials, and the implementation of innovative organizational management techniques.

Despite its longstanding presence in economic literature, the concept of "urban innovation level" remains somewhat nebulous within ongoing academic discourse. In China, however, a widely acknowledged framework for evaluating urban innovation emerged in the "*China Urban and Industrial Innovation Capability Report*". The Urban Innovation Index was a notable element of this report as it seeks to quantify the intangible capital stock of each city through a stock index adjusted by patent value. This innovative approach provides a structured means to gauge and compare the innovation potential across different urban landscapes within China.

2.1. The key factors influencing urban innovation: A multi-dimensional review

Urban innovation levels have become a focal point of research across numerous disciplines including management studies, economics, and geography. Scholars are dedicated to unravelling the complex factors and operational mechanisms influencing urban innovation levels. Beyond housing market variables such as property prices and land values, existing literature emphasises the need for a comprehensive examination across socio-economic, political-economic, historical, and cultural dimensions to capture the systemic drivers of innovation. These multidimensional factors do not operate in isolation but interact to collectively shape urban innovation. However, prevailing research predominantly offers static descriptions, lacking dynamic chain-mediated analysis – thereby providing the theoretical entry point for this study.

At the socio-economic level, economic growth, educational investment, and human capital agglomeration serve as core engines. The positive interaction between educational attainment and population density significantly enhances innovation output. This occurs because high educational agglomeration fosters knowledge spillovers and entrepreneurial dynamism, explaining approximately 30% of patent variation. Moderate inequality stimulates competitive innovation, yet extreme inequality inhibits talent mobility, resulting in a negative net effect at a threshold. More recently, Jin et al. (2023) further deepened this dimension using data on highly skilled youth migration in Zhejiang Province. They revealed that tolerance of housing unaffordability, while temporarily buffering human capital outflow, leads to a 10–15% decline in high-tech human capital density over the long term, thereby indirectly suppressing urban innovation. Though confined to provincial-level samples, this study's heterogeneity analysis provides micro-level evidence supporting the national chain pathway (housing → human capital → innovation) examined herein, yet it does not explore regional dynamics or policy thresholds.

The political-economic dimension focuses on institutional environments and policy interventions. Government subsidies and fiscal support for R&D can amplify innovation. However, corruption or regulatory distortions generate negative externalities and reduce policy efficiency. Political stability and local autonomy enhance regional disparities in urban innovation indices by reducing transaction costs. Within Chinese research, Lin et al. (2021) complement this perspective with a panel data analysis, using Chinese urban evidence to validate a chained pathway where housing prices inhibit innovation output via talent mobility intermediation. They emphasise that political intervention can mitigate crowding-out effects, though without exploring heterogeneity. This complements the present study's quantification of national pathway significance via IV-2SLS, highlighting the need for regionally adaptive innovation in policy design.

Historically and culturally, innovation is profoundly shaped by path dependence and cultural diversity. Cultural inclusivity serves as the 'super engine' of innovative cities, as cultural fusion and social networks bolster resilience. Historical legacies sustain innovation resilience, yet cultural conservatism hinders disruptive innovation. Historical administrative centres benefit from cultural capital accumulation, though policy intervention is required to overcome inertia inhibiting digital innovation. Gu and Jie (2024) recently expanded this discourse by examining how housing prices in 'dream cities' crowd out talent and weaken urban innovation. Empirical evidence shows that a 10% increase in housing prices leads to a 5.2% decline in innovation patents, highlighting how historical trajectories amplify cultural friction. However, this study lacks quantification of non-linearity and affordability indicators. This study fills the dynamic gap in the literature through Bootstrap mediation tests and regional heterogeneity analysis. It reveals, for the first time at a national scale, the policy thresholds of chain mechanisms, thereby highlighting its theoretical contribution within multidimensional interactions. Compared to the preliminary chain analyses by Jin et al. (2023), Lin et al. (2021), and Gu and Jie (2024), this paper integrates supply-demand dynamics with affordability, achieving a leap from static heterogeneity to dynamic mediation.

2.2. The driving effect of the housing market on urban innovation

The rise in land prices signifies an increase in urban land value, thereby generating greater land revenue for governments. These funds can be strategically allocated to enhance urban infrastructure, encompassing transport, communications, education, and healthcare. Such improvements foster an ideal environment for innovation. Research consistently indicates that market-oriented land systems primarily elevate urban innovation capacity through financing and selection effects (Zhang et al., 2022; Cheng et al., 2022). Moreover, distortions in land prices can expand regional innovation capacity by increasing local government fiscal revenues and providing implicit subsidies to enterprises, with this lagged effect primarily realised through these channels (You et al., 2021).

Research on housing prices reveals that higher residential costs can enhance urban innovation capacity by attracting talent and stimulating local fiscal revenue growth (Ding et al., 2023). Additionally, He et al. (2022) observed that surging housing prices significantly elevated innovation outputs in high-tech sectors and non-state-owned enterprises. Nevertheless, this effect was not pronounced in non-high-tech sectors or state-owned enterprises. This indicates that rising housing prices exert a promotional effect on innovation capacity. Moreover, a statistically and economically significant positive correlation exists between innovation quality and housing price increases. Notably, this correlation arises from innovation quality driving property price increases rather than the reverse, with this effect being particularly pronounced in regions exhibiting low land supply elasticity (Beracha et al., 2022).

In recent years, the relationship between human capital and innovation has garnered significant academic attention. Human capital constitutes the core driver of all innovation activities (Caragliu & Del Bo, 2019). Increased labour mobility stimulates technological innovation among local firms, particularly in sectors emphasising design and high-quality innovation (Xu et al., 2024). Furthermore, the agglomeration effects generated by population mobility not only facilitate the transfer, diffusion, and spillover of knowledge, information, and technology, but also deepen urban specialisation. This drives industrial upgrading and optimisation, thereby enhancing a city's innovation capacity (Cui et al., 2021). The human capital theory proposed by American economist Schultz (1959) emphasises the pivotal role of talent in driving innovation, positing that human capital constitutes the primary determinant of innovation levels. Increases in human capital, particularly highly skilled human capital, significantly elevate a city's innovation capacity (Cooke, 2013; Strange et al., 2006).

2.3. The restraining effect of the housing market on urban innovation

Scholars have extensively investigated the impact of housing and land prices on urban innovation, with findings indicating both positive and negative effects. Beyond influencing innovation inputs and outputs, housing prices also affect the capacity to translate innovative outcomes into tangible results. Li et al. (2023) emphasise that the housing market's influence on urban innovation extends to real estate investment, human capital levels, and regional consumption capacity. Yu and Cai (2021) employed a simultaneous equation model to demonstrate an inverted U-shaped relationship between housing prices and urban innovation dynamism. As property values rise, innovation activity initially increases before subsequently declining. Ding et al. (2023) utilised a fixed-effects model to reveal that rising housing prices divert capital towards the property market and constrain household consumption capacity, thereby suppressing innovation capabilities in Chinese cities. Lin et al. (2021) noted that the positive correlation between housing prices and innovation outcomes alongside talent attraction gradually weakens, particularly in first-tier cities. This suggests potential crowding-out effects should price increases trigger bubbles. Their study, based on Chinese city panel data, empirically validated a chained pathway where housing prices inhibit innovation output via talent mobility—highly consistent with this research's core mechanism—though it lacked in-depth heterogeneity analysis.

From the perspective of land prices, scholars concur that elevated land costs may impede the formation and development of innovation ecosystems, particularly for start-ups and innovative enterprises that require low living and entrepreneurial expenses to thrive (Chu et al., 2024). Chau et al. (2021) concluded that rising property prices elevate residents' living costs, impede labour inflows, and consequently hinder the accumulation of urban human capital – a factor crucial for enhancing a city's innovative capacity.

However, researchers have yet to reach consensus on many aspects of these studies. Some scholars contend that while high housing and land costs may inhibit the formation and development of innovation ecosystems, they may simultaneously stimulate local innovation activity while hindering innovation in surrounding regions (Liu et al., 2024). They suggest that talent policies such as housing support can enhance the innovation capacity of non-first-tier cities, though the effectiveness of such policies may vary according to local circumstances (He et al., 2022).

2.4. Theoretical mechanisms and pathways through which the housing market affects innovation capacity

Although existing studies have confirmed the complex relationship between the housing market and innovation, the deeper theoretical mechanisms underlying this linkage remain insufficiently clarified. To reveal the internal logic of the chain mediation of "housing affordability–human capital–urban innovation" from a micro-level perspective, this study introduces the Rosen–Roback model and labor sorting theory as its core theoretical foundations.

According to the Rosen–Roback spatial equilibrium model (Roback, 1982), labor mobility across cities is driven by the equalization of real wages, defined as the difference between nominal wages and housing costs (as well as local amenities). When housing prices in a city rise faster than wage growth generated by productivity improvements or utility compensation from urban amenities, real wages decline, leading to labor outflows. However, this classical model assumes homogeneous labor and therefore cannot fully explain why innovation output may exhibit nonlinear declines.

Building on this framework, heterogeneous labor sorting theory further distinguishes the location choices of high-skilled and low-skilled workers (Moretti, 2011; Diamond, 2016). Innovation activities rely primarily on high-skilled human capital (the "creative class"), whose members are generally more sensitive to quality of life and real purchasing power. When housing affordability deteriorates (i.e., when the price-to-income ratio becomes excessively high), high-skilled workers face higher opportunity costs. Under the sorting mechanism, if the congestion costs induced by high housing prices exceed the skill premium generated by agglomeration effects, high-skilled talent will be the first to "vote with their feet" and relocate to cities offering better cost-performance ratios. This phenomenon of "reverse talent selection" explains why the crowding-out effect of housing burdens is more pronounced for high-skilled workers than for ordinary labor, ultimately leading to a cliff-like or nonlinear decline in urban innovation capacity once housing prices exceed a critical threshold.

Beyond these theoretical mechanisms, prior studies have also identified multiple empirical transmission channels. Chau et al. (2021) find that surging urban housing prices significantly weaken urban innovation capacity by distorting the structure of human capital agglomeration. Pradana et al. (2020) emphasize the critical role of human capital in promoting firm innovation, a role that is highly vulnerable to erosion by rising living costs. Chu et al. (2024) examine the nonlinear characteristics of price mechanisms and show that once housing price growth exceeds 2.82%, its negative impact on firm innovation intensifies significantly. Du et al. (2020) observe that constrained housing supply drives up prices, which in turn further restricts supply, leading to the spatial dispersion of industrial innovation and hindering urban innovation activities.

Notably, these mechanisms exhibit heterogeneity across different types of cities. Yin et al. (2023) find that the spatial correlation between urban housing prices and urban innovation and quality has been strengthening, indicating the presence of complex spatial lock-in effects. Ding et al. (2023) further identifies a dual effect: on the one hand, high housing prices in the early stages of development may attract high-productivity firms through a screening effect; on the other hand, as prices continue to rise, capital shifts from the real economy to the real estate sector ("from real to virtual"), constraining household consumption and R&D investment and thereby suppressing innovation. This perspective aligns with the hypothesis proposed in this study based on labor sorting theory—that housing affordability, by regulating the inflow and outflow of human capital, acts as a "valve" determining the rise and decline of urban innovation.

In addition, the mediating roles of land supply and financial development have also been identified. A reduction in land supply intensifies the inhibitory effect of housing prices on firm innovation, whereas higher levels and efficiency of financial development can mitigate this suppression (Liu & Shi, 2019). The interaction between supply and demand remains closely tied to urban housing prices, giving rise to price tensions and cyclical fluctuations. Net population inflows into large cities, combined with limited residential land supply, lead to housing shortages and rising prices. In contrast, smaller cities with sparse populations and abundant land face housing oversupply and significant surpluses. Existing studies consistently show that housing prices have a significant impact on urban innovation, with most scholars concluding that high housing prices ultimately inhibit innovation through the loss of human capital (Rong et al., 2016).

2.5. Measurement of relevant indicators: Housing supply-demand ratio and housing affordability

To deepen the empirical analysis of housing market dynamics, this study introduces the housing supply-demand ratio as a key mediating indicator to capture the transmission of supply-demand imbalances along innovation pathways. Specifically, residential real estate development investment is selected as the housing supply indicator, residential commodity housing sales area as the housing demand indicator, and the ratio of building construction area to average residential commodity housing sales area to measure the housing supply-demand ratio. Figure 1 illustrates the average values and growth rates of the housing supply-demand ratio across regions from 2005 to 2020. From a national perspective, the indicator exhibits low overall variability but significant regional heterogeneity: rapid growth occurred in 2007–2008, 2009–2012, and 2013–2014, with the peak average in 2014. Regionally, the eastern region's average exceeds the national and others, with a 40.74% growth rate peaking in 2014; the central region shows overall negative growth, with fast acceleration in 2007–2008 and sharp declines in 2008–2010, peaking in 2008; the western region trends downward, with growth in 2007–2008 and 2009–2010, declines in 2008–2009 and 2010–2011, peaking in 2014; the northeastern region grows positively, accelerating in 2013–2015 and decelerating in 2015–2016, peaking in 2015.

In summary, the national housing supply-demand ratio has declined since 2015, influenced by policy regulations that have stabilized real estate market development. Regional comparisons reveal the east consistently above average; pre-2013, the central outperformed the west and northeast, but post-2013, the northeast surpassed them; growth rates are positive in the east and northeast and negative in the central and west (central lowest). These dynamics illuminate the housing supply-demand ratio's role in chain mediation: tight supply initially reinforces driving effects, but prolonged imbalances amplify suppression risks, aligning closely with this study's pathway (supply-demand ratio → affordability → human capital). Data are sourced from the China Urban Statistical Yearbook, China Regional Economic Statistical Yearbook, EPS database, and provincial/municipal statistical yearbooks; averages and growth rates were calculated by the author.

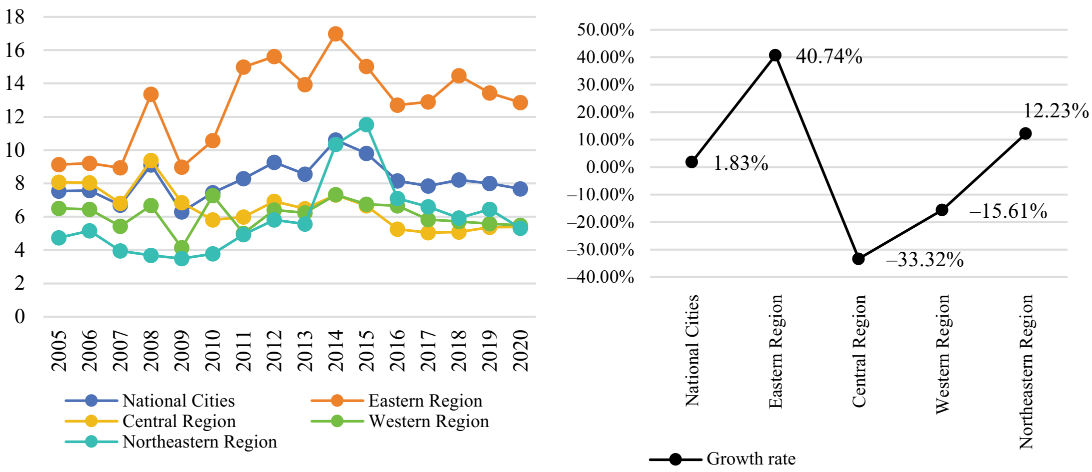

Figure 1. Average and growth rate of housing supply and demand ratio in different regions from 2005 to 2020

Concurrently, measuring housing affordability is central to understanding affordability mechanisms. Academia primarily employs two methods: the ratio method and the residual income approach (RIA). The ratio method is operationally simple with readily available data, suitable for cross-regional comparisons (Whitehead, 1991), featuring indicators like PIR and HAI (National Association of Realtors); however, it overlooks non-housing factors and income heterogeneity. The residual income approach is logically rigorous, emphasizing opportunity costs (Stone, 1993; Hancock, 1993), ideal for intra-regional low-income analyses (Bramley & Karley, 2005), but data-intensive and unsuitable for cross-regional use (Mak et al., 2007; Huang, 2022). Some studies integrate both (Yin et al., 2022), revealing dominant roles of real estate and demographic factors.

Given data gaps in rents and expenditures, this study adopts the ratio of average residential commodity housing sales price to urban per capita disposable income as the housing affordability indicator. This facilitates national comparisons and bolsters empirical chain mediation testing, filling gaps in existing literature on regional dynamics and nonlinear thresholds.

In summary, urban innovation levels are influenced by numerous factors, including economic development, financial infrastructure, and human capital. High housing and land prices exert dual effects on urban innovation, both promoting and constraining innovation. Improvements in urban economic development, infrastructure, and the digital economy positively contribute to urban innovation levels. Financial development, openness, government support, talent policies, and infrastructure construction are key drivers of urban innovation. Population mobility also plays a vital role in elevating urban innovation levels through agglomeration effects and the accumulation of high-skilled human capital.

This study extends existing knowledge in two key ways: first, by revealing how the housing market influences innovation through chain-mediated mechanisms, exploring the chain mediation among housing supply-demand dynamics, affordability, and human capital levels to elucidate pathways impacting urban innovation levels, offering a novel perspective on complex intermediary effects in urban development—compared to preliminary chain explorations in Lin et al. (2021) and Gu and Jie (2024), this study quantifies national pathway significance via Bootstrap mediation testing and IV-2SLS, filling nonlinearity and heterogeneity gaps while incorporating regional housing supply-demand ratio dynamics for mechanism robustness; second, by uncovering heterogeneity effects across cities, accounting for regional differences to analyze varied responses of regions and city types to chain mediation, aiding deeper insights into local housing markets and innovation level characteristics/challenges for targeted policymaking—this surpasses Jin et al. (2023) provincial tolerance analysis, pioneering distinctions between mid-western "positive transmission" and eastern "crowding-out dominance", and revealing policy thresholds via refined housing affordability metrics.

3. Theoretical model of the housing market's influence on urban innovation

3.1. Ability to pay effect

In the initial phase of rising house prices, the discrepancy between the growth rate of housing prices and residents' income levels remains modest. At this stage, the positive implications of decreasing housing affordability on urban innovation outweigh the negative repercussions. This situation catalyzes regional economic growth, bolsters government fiscal revenue, and facilitates heightened investment in innovative endeavors. Simultaneously, it fuels the evolution and refinement of urban industrial frameworks and fortifies infrastructure, thereby refining the innovation landscape. Additionally, on an individual level, the increase in the housing-to-income ratio motivates residents to intensify their efforts owing to housing-related concerns, thereby amplifying their work enthusiasm and ingenuity, consequently fostering urban innovation. From a corporate standpoint, the surge in the housing-to-income ratio incentivizes businesses to expedite innovation initiatives and upgrades, compelling augmented investment in pioneering research and development endeavors, thereby elevating urban innovation standards (Kiyotaki & Moore, 1997).

As the ratio of house prices to income continues to rise, the affordability of housing payments for residents diminishes. With their constrained income levels, residents increasingly grapple with the challenge of inflated housing prices. At this stage, the adverse impact of housing affordability on urban innovation gradually surpasses the positive effects. The surge in the ratio of house prices to income precipitates crowding-out effects on urban innovation, primarily impinging upon innovation funding and human capital.

The escalation of the house price-to-income ratio catalyzes an increase in capital inflows (including personal savings and financial institution loans) into the housing market, thereby displacing funds from innovation sectors. This phenomenon impedes the elevation of urban innovation standards (Wang et al., 2017; Lu et al., 2019). As housing affordability continues to deteriorate, an increasing number of individuals who possess valuable human capital opt to leave cities due to housing affordability concerns. This serves to undermine the aggregation of urban talent and the progression of urban innovation levels. Moreover, exorbitant house prices have been found to precipitate a crowding-out effect on young professionals across 235 cities in China (Ding et al., 2023).

Based on the aforementioned theoretical analysis, this paper posits the following hypothesis:

H1: *Housing affordability has an effect on urban innovation level.*

3.2. Human capital effect

Previous studies have demonstrated a close interconnection between the dynamics of housing supply and demand and urban housing prices, wherein fluctuations in these factors exert varying influences on housing prices (Torab, 2018). Additionally, there is a strong correlation between housing affordability and housing prices, where elevated housing prices, alongside stagnant income levels, drive up the ratio of housing prices to income, thereby reducing residents' ability to afford housing.

Human capital plays a pivotal role in fostering innovation (Li & Zhang, 2020; Caragliu & Del Bo, 2019), as it constitutes the bedrock of innovative endeavors, predominantly propelling innovative practices. Urban innovation levels are contingent upon the concentration of talent within a city; that is, locales with a higher prevalence of highly skilled human capital typically exhibit greater levels of innovation. The influx of talent into a city is influenced by a wide range of internal factors, including the city's economic development, infrastructure, income levels, and governmental policies. Elevated housing prices precipitate a decline in housing affordability, disproportionately affecting recent graduates who struggle to afford excessive urban housing prices on modest incomes. Consequently, recent graduates are increasingly opting to settle in smaller cities, avoiding metropolises like Beijing, Shanghai, Guangzhou, and Shenzhen (Xia, 2011). Hence, the erosion of housing affordability can be perceived as exerting a displacement effect on human capital, consequently impacting urban innovation levels.

From the foregoing analysis, it becomes apparent that the relationship between housing supply and demand significantly influences housing affordability, thereby shaping the level of human capital—an indispensable factor in driving urban innovation. Thus, we posit the existence of a chain-like relationship among housing supply-demand dynamics, housing affordability, human capital levels, and urban innovation levels. Changes in housing supply and demand serve as fundamental catalysts for fluctuations in housing prices. An imbalance in the housing market, reflected by an elevated housing supply-demand ratio, leads to market instability and cyclical fluctuations in housing prices. The sustained escalation of housing prices in recent years has rendered it increasingly difficult for residents to afford housing on limited incomes, thereby undermining housing affordability. Consequently, the rise in housing prices exacerbates the cost of living, impeding population migration. Population influx serves as a wellspring of human capital for urban technological innovation (Ren, 2022). As housing affordability wanes, it has a displacement effect on the level of human capital, impeding the aggregation of urban talent and, thereby, curtailing urban innovation levels. Consequently, this study proposes the following research hypothesis:

H2: *An increase in the ratio of housing supply and demand will inhibit the level of human capital and the level of urban innovation by weakening the affordability of housing.*

Figure 2 below illustrates the pathway diagram of the mechanism through which the housing supply-demand relationship and affordability influence urban innovation levels.

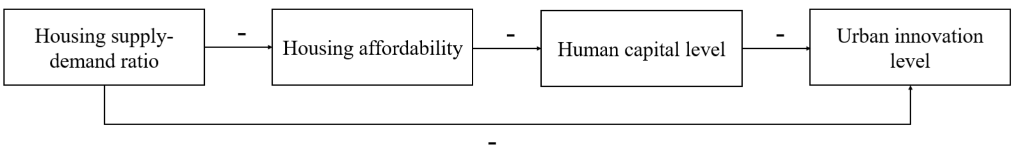

Figure 2. A road map for the influence mechanism of housing supply and demand and affordability on urban innovation level

3.3. Models

Based on the above theoretical analysis and data collation, this paper builds a model of housing supply and demand ratio, housing affordability and human capital effect on urban innovation level. To eliminate the influence of heteroscedasticity and increase the comparability of data, all variables were treated logarithmically in this study, and the regression model applied was as follows:

$$lnhaf_{it} = \beta_0 + \beta_1 lnstd_{it} + \beta_2 C_{it} + \delta_{it} + \varphi_{it} + \varepsilon_{it}; \quad (1)$$

$$lnhc_{it} = \gamma_0 + \gamma_1 lnstd_{it} + \gamma_2 lnhaf_{it} + \gamma_3 C_{it} + \delta_{it} + \varphi_{it} + \varepsilon_{it}; \quad (2)$$

$$lninn_{it} = \mu_0 + \mu_1 lnstd_{it} + \mu_2 lnhaf_{it} + \mu_3 lnhc_{it} + \mu_4 C_{it} + \delta_{it} + \varphi_{it} + \varepsilon_{it}, \quad (3)$$

where: i denotes city; t denotes year; $lninn_{it}$ represents urban innovation level; $lnhaf_{it}$ denotes housing affordability; $lnstd_{it}$ indicates housing supply-demand ratio; $lnhc_{it}$ signifies human capital level; C_{it} represents control variables (including regional economic development level, financial development level, etc.); δ_{it} denotes individual effect; φ_{it} denotes time effect; ε_{it} denotes error term; $\beta_{0\text{-}2}$, $\gamma_{0\text{-}3}$, $\mu_{0\text{-}4}$ denote coefficients respectively.

Within the chained multiple mediation effect model, effects can be categorised into independent mediation effects and chained mediation effects. Independent mediation effects comprise two pathways: 'housing supply-demand ratio → weakening housing affordability → suppressing urban innovation level' and 'housing supply-demand ratio → weakening human capital level → suppressing urban innovation level'. These may be denoted as independent mediation effect 1 and independent mediation effect 2, with magnitudes $\beta_1\mu_2$ and $\gamma_1\mu_3$ respectively. Chain mediation manifests as 'housing supply-demand ratio → diminished housing affordability → weakened human capital → suppressed urban innovation level', with magnitude $\beta_1\gamma_2\mu_3$. Thus, the overall mediation effect is $\beta_1\mu_2 + \gamma_1\mu_3 + \beta_1\gamma_2\mu_3$.

The primary focus of this study is to examine the significance of the chained mediating effect, with independent mediating effects receiving secondary attention. Regarding mediation testing methodology, when coefficients are significant, stepwise testing yields stronger results than coefficient product tests; the latter is only warranted when coefficients are insignificant. Drawing upon the novel mediation effect testing procedure, this study adopts the following approach for chained mediation effects: if β_1, γ_2, and μ_3 are significant, the chained mediation effect is deemed significant; conversely, the Bootstrap method is employed to test the coefficient product.

4. Variable selection, indicator construction, and data description

4.1. Variable selection and indicator construction

This paper employs the housing supply-demand ratio as the core explanatory variable, urban innovation level as the dependent variable, and housing affordability and human capital level as mediating variables. The human capital level is measured by the number of students enrolled in higher education institutions per 10,000 people.

(1) Dependent variable

Based on the literature review of measurement indicators for urban innovation capacity, previous studies have predominantly used patent data to gauge urban innovation levels. However, single indicators often suffer from substantial limitations. Consequently, some scholars have developed comprehensive evaluation systems for innovation levels from perspectives such as innovation inputs, outputs, and environments. Compared to single indicators, these comprehensive systems more holistically reflect a city's innovation level. Currently, most research adopts innovation indices to measure urban innovation levels, with two particularly prominent ones being the Urban Innovation Level Index from the China Urban and Industrial Innovation Capability Report 2017 and the Entrepreneurship and Innovation Index compiled by the Peking University Business Intelligence Research Center. Considering data timeliness, this paper selects the Entrepreneurship and Innovation Index compiled by the Peking University Business Intelligence Research Center as the measure for urban innovation level. This index incorporates three critical factors for innovation—people, capital, and technology—and constructs a comprehensive evaluation system encompassing five dimensions and seven indicators, enabling a more comprehensive reflection of urban innovation levels. The measurement indicators for urban innovation levels are presented in Table 1.

Table 1. Index measure of urban innovation level

Variable	Primary indicator	Secondary indicator
Urban innovation level (inn)	Number of new enterprises	Number of newly registered enterprises
	Attraction of foreign investment	Number of new foreign legal person investments
	Attraction of venture capital	Number of enterprises receiving new venture capital
	Number of patent authorizations	Number of new invention patent authorizations
		Number of new utility model patent publications
		Number of new design patent publications
	Number of trademark registrations	Number of new trademark registrations

(2) Control variables

This paper selects the following variables as control variables:

Economic development level (pgdp): Gross Domestic Product (GDP) represents the final outcomes of production activities by all resident units in a country (or region) over a specific period. GDP is a crucial indicator for measuring the economic development level of a country or region. This paper uses per capita regional GDP (pgdp) to measure the economic development level.

Financial development level (fin): The financial development level plays a vital role in a city's socio-economic development. Whether for individuals, enterprises, or the nation, economic activities require funding support, and finance's primary function is to allocate funds across society and industries, facilitating capital flow for economic entities of all sizes. This paper uses the ratio of financial deposits and loans to GDP to measure the financial development level.

Industrial structure (ind): Industrial structure significantly influences national economic development and resource allocation. Optimizing and upgrading industrial structure can achieve economic growth and enhance resource allocation efficiency. This paper uses the ratio of tertiary industry output to secondary industry output to measure industrial structure.

Urbanization level (urb): Cities serve as centers for regional science, technology, and culture, and the urbanization level is a key manifestation of a region's overall development. This paper uses the urbanization rate to measure the urbanization level, calculated as the ratio of urban resident population to the total resident population at year-end.

Degree of openness (open): Openness to the outside world plays a crucial role in a city's development, promoting exchanges in culture, technology, production, and other aspects among countries and regions. The degree of a city's external openness reflects its development level. This paper uses the ratio of total import and export volume to GDP to measure the degree of openness.

Government intervention (gov): Government intervention significantly affects urban economic development and resource allocation. The extent of a city's government's involvement in the local economy—where a higher proportion indicates a stronger role and greater capacity to mobilize social resources—is measured by the ratio of government fiscal expenditure to GDP in that year.

Technological level (tec): Science and technology represent the concentrated embodiment and key hallmark of advanced productive forces, serving as the primary productive force. A city's technological level profoundly impacts its urban innovation level. This paper uses the ratio of science and technology expenditure to total fiscal expenditure to measure the technological level.

Infrastructure level (inf): The infrastructure level is a critical factor in urban development. Considering the influencing factors of the dependent variable, this paper uses the number of library books per 10,000 people to measure the infrastructure level.

4.2. Data description

The primary objective of this study was to develop in-depth insights into the intricate mechanisms linking housing supply, demand, affordability, and urban innovation levels. In line with this, the ratio of housing supply to demand was adopted as the principal explanatory variable, urban innovation level as the dependent variable, and housing affordability and human capital level as intermediary variables. The dataset encompassed panel data from 284 prefecture-level cities across China spanning 2005 to 2020. The urban innovation index was sourced from the China Regional Innovation and Entrepreneurship Index compiled by the Enterprise Big Data Research Center of Peking University, while the other data were obtained from various official sources, including the China City Statistical Yearbook, China Regional Economic Statistical Yearbook, EPS database, and provincial and municipal statistical yearbooks. Due to the extensive geographical and temporal scope, some data points were missing, necessitating the use of linear interpolation to address these gaps.

(1) Housing affordability. This paper measures housing affordability by the ratio of average residential commodity housing sales price to per capita disposable income of urban residents. A higher ratio indicates weaker residents' housing affordability, and vice versa. The specific data descriptions are shown in the Table 2.

(2) Housing supply-demand ratio (std). The housing supply-demand ratio is derived from the ratio of building construction area to average residential commodity housing sales area. When the ratio is closer to 1, it indicates a more balanced housing market supply and demand; a higher ratio signifies that housing supply far exceeds demand, leading to greater market imbalance. A higher ratio reflects weaker residents' housing affordability, and vice versa—though for supply-demand, emphasis is on imbalance thresholds.

Table 2. Data description of housing affordability

Region type	Variable	Symbol	Variable description (Unit)	Mean	Std.	Min	Max
National cities	Housing affordability	*haf*	Average residential commodity housing sales price × 100 / Per capita disposable income of urban residents (%)	18.481	8.140	1.356	196.184
Eastern region				23.014	10.041	8.336	97.516
Central region				16.679	6.636	6.699	196.184
Western region				16.291	6.385	1.356	177.789
Northeastern region				16.664	4.428	4.177	35.856
innovative pilot cities				22.440	9.299	1.356	96.346
Non-innovative pilot cities				17.060	7.169	1.998	196.184

Table 3. Data description of human capital levels

Region type	Variable	Symbol	Variable description (Unit)	Mean	Std.	Min	Max
National cities	Human capital level	*hc*	Number of students enrolled in higher education institutions per 10,000 people (Persons)	172.692	229.737	0.576	1326.915
Eastern cegion				213.133	249.784	3.742	1326.915
Central cegion				168.408	237.220	2.084	1310.745
Western cegion				148.958	221.466	0.576	1311.241
Northeastern region				139.115	151.713	1.334	690.420
innovative pilot cities				390.329	319.126	19.451	1326.915
Non-innovative pilot cities				94.592	109.975	0.576	1197.822

(3) Human capital level is measured by the number of students enrolled in higher education institutions per 10,000 people. The human capital variables are described in Table 3. Unit root tests on the human capital level reveal that after first-order differencing, the *p*-values are all less than 0.01, significantly rejecting the null hypothesis of a unit root, allowing for subsequent empirical testing.

5. Empirical analyses

5.1. Regression results

To empirically test the relationships, a bidirectional fixed-effect model was employed. This choice is also supported by the results of the panel unit root tests, cointegration tests, and the Hausman test. Considering the potential endogeneity arising from reverse causality (such as the bidirectional interaction between urban innovation and the housing market), instrumental variables were introduced to enhance the accuracy of the empirical findings. Specifically, the one-stage lag of the core explanatory variable was selected as the instrumental variable to mitigate endogeneity concerns. This selection follows the principle that valid instrumental variables must satisfy both exogeneity and relevance—namely, they should be uncorrelated with the disturbance term while remaining strongly correlated with the endogenous explanatory variable. Drawing on existing literature, lagged terms of endogenous variables are widely used as suitable instruments; hence, this study employs the one-period lag of the core explanatory variable as the instrumental variable.To ensure the adequacy of the instrumental variables, a weak instrumental variable test was conducted. The outputs of this test revealed that all F-values exceeded 10 with a *p*-value of 0.0000, indicating a significant rejection of the null hypothesis of weak instrumental variables. Consequently, it was concluded that the chosen instrumental variables were suitable and that weak instrumental variable problems were not present. Each model presented in this paper incorporated the same number of instrumental variables as endogenous explanatory variables, thus achieving just identification without the need for excessive identification tests. The empirical analysis spanned Ordinary Least Squares (OLS), Two-Way Fixed Effects (Tw-FE), and Instrumental Variable Two-Stage Least Squares (IV-2SLS) methods. The results presented in Table 4 demonstrate consistency in the signs and significance levels of the coefficients α_1, β_2, and γ_3 across all models, indicating robust empirical outcomes.

Column (4)–(6) of Table 4 corresponded to the regression results for Equations (1), (2) and (3) respectively. In column (4) of Table 4, housing affordability served as the dependent variable. The coefficient for the influence of the housing supply and demand ratio on housing affordability was estimated at 0.052, significant at the 1% level. This suggests that an increase in the housing supply and demand ratio leads to a rise in the housing price-to-income ratio, thereby undermining housing affordability. The escalation in the housing supply and demand ratio triggers market fluctuations, resulting in periodic fluctuations in housing prices. In scenarios where residents' income levels remain relatively stable while housing prices undergo substantial changes, an elevated housing supply and demand ratio tends to constrain residents' ability to afford housing payments.

Column (5) of Table 4 focused on human capital level as the dependent variable. The coefficient for the influence of the housing supply and demand ratio on human capital level was estimated at –0.004, insignificantly different from zero. This indicates that the housing supply and demand ratio exerts no significant influence on human capital level. However, the coefficient for the influence of housing affordability on human capital level was estimated at –0.065, significant at the 1% level. This implies that deteriorating housing affordability negatively impacts human capital level. The increasing housing price-to-income ratio diminishes housing affordability, rendering it challenging for residents to afford rising housing prices with their existing income levels. Consequently, the decline in urban housing affordability exacerbates a crowding-out effect on human capital accumulation.

Column (6) of Table 4 investigated urban innovation level as the dependent variable. The coefficient for the influence of the housing supply and demand ratio on urban innovation level was estimated at –0.049, significant at the 1% level. Additionally, the coefficient for the influence of housing affordability on urban innovation level was estimated at 0.020, significant at the 10% level, while the coefficient for the influence of human capital level on urban innovation level was estimated at 0.076, significant at the 1% level.

Table 4. Test results of chain multiple mediation effects

Variable	OLS			Tw-FE			IV-2SLS		
	(1) lnhaf	(2) Lnhc	(3) lninn	(4) lnhaf	(5) lnhc	(6) lninn	(7) lnhaf	(8) lnhc	(9) lninn
lnstd	0.072*** (13.13)	–0.053*** (–3.14)	–0.007* (–1.84)	0.052*** (8.16)	–0.004 (–0.38)	–0.049*** (–9.74)	0.062*** (8.30)	–0.066*** (–3.21)	–0.004 (–0.90)
lnhaf		0.237*** (5.33)	–0.015 (–1.48)		–0.065*** (–2.59)	0.020* (1.66)		0.293*** (5.05)	–0.027* (–1.88)
lnhc			0.043*** (12.28)			0.076*** (10.33)			0.039*** (8.38)
lnpgdp	–0.071*** (–7.12)	0.434*** (14.52)	0.390*** (54.67)	0.004 (0.17)	0.291*** (7.83)	0.468*** (26.00)	–0.081*** (–7.23)	0.414*** (11.32)	0.381*** (44.55)
lnfin	0.245*** (17.63)	1.043*** (24.27)	0.130*** (12.17)	0.034 (1.47)	0.155*** (4.10)	0.180*** (9.86)	0.245*** (16.29)	1.032*** (21.63)	0.122*** (10.73)
lnind	0.071*** (6.78)	0.148*** (4.71)	–0.027*** (–3.74)	–0.019 (–1.24)	0.029 (1.13)	–0.026** (–2.12)	0.078*** (6.08)	0.164*** (4.84)	–0.019** (–2.10)
lnurb	0.006 (0.33)	–0.094 (–1.64)	0.050*** (3.77)	–0.008 (–0.36)	0.023 (0.67)	0.129*** (7.85)	–0.011 (–0.55)	–0.096 (–1.42)	0.056*** (3.40)
lnopen	0.047*** (13.81)	–0.042*** (–4.02)	0.029*** (11.77)	0.019*** (3.31)	–0.021** (–2.23)	0.021*** (4.80)	0.048*** (11.76)	–0.053*** (–4.59)	0.026*** (9.28)
lngov	–0.094*** (–8.65)	–0.863*** (–26.23)	0.161*** (19.52)	0.083*** (3.73)	–0.039 (–1.08)	0.203*** (11.57)	–0.107*** (–8.59)	–0.886*** (–22.86)	0.170*** (15.95)
lntec	0.085*** (15.88)	0.127*** (7.70)	–0.000 (–0.05)	0.026*** (4.36)	–0.050*** (–5.13)	–0.068*** (–14.31)	0.089*** (14.14)	0.131*** (6.92)	0.009** (2.25)
lninf	–0.007 (–1.00)	0.165*** (7.79)	–0.050*** (–10.03)	0.007 (0.89)	0.050*** (3.92)	0.015** (2.50)	–0.002 (–0.31)	0.161*** (7.82)	–0.051*** (–8.56)
Constant	1.666*** (23.53)	–5.868*** (–26.16)	–0.846*** (–15.07)	2.233*** (7.56)	0.367 (0.75)	–2.664*** (–11.34)	1.805*** (20.88)	–5.704*** (–22.25)	–0.791*** (–9.93)
Obs.	4544	4544	4544	4544	4544	4544	4260	4260	4260
Individual fixed effect				Yes	Yes	Yes			
Time fixed effect				Yes	Yes	Yes			
R^2	0.381	0.553	0.785	0.101	0.441	0.815	0.387	0.550	0.770

Note: The data in the table was calculated using Stata. *, **, and *** are significant at the significance levels of 10%, 5%, and 1%, respectively, with a *t*-values in parentheses.

Table 5. Test results of the mediation effect of the Bootstrap method

Type of intermediary effect	Intermediate effect size	95% confidence interval	
		LLCI	ULCI
Chain mediation effect	–0.001* (–1.91)	–0.0008	–0.0001
Population mediating effect	–0.002*** (–2.90)	–0.0030	–0.0021

Note: *, and *** represent significance at the 10% and 1% significance levels, respectively, with *Z*-values in parentheses, and LLCI and ULCI represent the lowest and highest values of the 95% confidence interval, respectively.

The empirical results in columns (4)–(6) of Table 4 indicated significance for α_1, β_2, and γ_3. Further testing using the Bootstrap method (Table 5) revealed that the 95% confidence interval corresponding to the chain mediation effect excluded zero. Thus, based on the analysis, it was concluded that a chain intermediary effect exists. Specifically, an increase in the housing supply and demand ratio restrains human capital level by eroding housing affordability, thereby inhibiting urban innovation levels.

5.2. Heterogeneity analysis

To further analyse the contextual dependence of the chained mediating effect of housing supply-demand ratios on urban innovation levels across different city types, we introduce separate sample regressions for innovative pilot cities and non-innovative pilot cities. This not only validates the robustness of the overall framework but also reveals how institutional environments and developmental stages shape the reversal of mediating pathways—a novel heterogeneity beyond existing literature that fills the gap in the static descriptions of the 'Dream City' negative feedback loop in studies such as Gu and Jie (2024) and others' static descriptions of negative feedback in 'dream cities,' offering dynamic policy entry points.

Based on the classification of innovative pilot cities in 2020, after excluding Lhasa, a total of 75 innovative pilot cities were identified, resulting in 1,200 observations.

Table 6. Data description of innovative pilot cities and non-innovative pilot cities

City type	Variable	Symbol	Mean	Std.	Min	Max
Innovative pilot cities	Urban innovation level	*inn*	84.681	14.965	24.030	100.000
	Housing supply level	*hs*	4493856.000	5172829.000	65970.000	32500000.000
	Housing demand level	*hd*	747.857	689.961	35.562	5452.650
	Housing supply-demand ratio	*std*	12.941	17.622	1.073	158.646
	Economic development level	*pgdp*	64874.730	36596.240	5497.000	203489.000
	Financial development level	*fin*	297.259	148.517	84.217	1250.790
	Industrial structure	*ind*	106.615	60.439	16.517	534.817
	Urbanization level	*urb*	63.105	16.092	11.410	100.000
	Degree of openness	*open*	36.733	46.723	0.454	325.304
	Government intervention	*gov*	12.746	4.439	4.265	30.694
	Technological level	*tec*	249.713	200.990	9.500	1627.290
	Infrastructure level	*inf*	8801.947	7421.666	511.617	85847.250
Non-innovative pilot cities	Urban innovation level	*inn*	64.896	20.489	7.527	99.933
	Housing supply level	*hs*	813774.600	1002855.000	2934.000	10100000.000
	Housing demand level	*hd*	211.304	200.014	0.870	1745.550
	Housing supply-demand ratio	*std*	6.487	7.068	1.013	183.218
	Economic development level	*pgdp*	33884.740	24803.920	2396.000	256877.000
	Financial development level	*fin*	199.824	87.429	50.806	2130.150
	Industrial structure	*ind*	90.949	51.634	9.432	948.222
	Urbanization level	*urb*	46.828	15.083	11.510	96.480
	Degree of openness	*open*	13.266	25.798	0.003	349.886
	Government intervention	*gov*	19.861	10.979	4.262	148.516
	Technological level	*tec*	101.172	104.731	2.650	2068.350
	Infrastructure level	*inf*	4206.637	9205.814	134.818	440109.000

Note: The data in the table was calculated using Stata.

There are 209 non-innovative cities with a total of 3,344 observations. The data description for different types of cities is shown in Table 6.

Table 7 presents the heterogeneity test results for innovative and non-innovative pilot cities. In Columns (1)–(6) of Table 7, both city types exhibit positive and 1% level significant coefficients for the housing supply-demand ratio's impact on housing affordability, indicating that supply-demand imbalances universally exacerbate payment pressures. The coefficient for housing affordability's effect on human capital levels is negative and 10% level significant, reflecting consistent crowding-out effects. The coefficient for human capital levels on urban innovation is positive and significant at the 1% level, confirming the transmission core of human capital agglomeration. These benchmark consistencies establish a universal foundation for chain mediation, yet key heterogeneity lies in path directionality: to enhance accuracy, we employ Bootstrap methods to validate mediation significance.

Table 8 presents Bootstrap mediation effect test results across different city types. Results indicate that the 95% confidence intervals for all mediation effects across both city types do not contain zero. Combined with the aforementioned coefficients, this confirms the overall significance of chain mediation effects. Specifically, within innovative pilot cities, an increase in the housing supply-demand ratio impedes urban innovation levels through a negative chain pathway: 'diminished housing affordability → suppressed human capital levels'. This stems from the 'crowding-out trap' in highly competitive environments: High housing prices amplify talent outflow, suppress knowledge spillovers, and create a vicious cycle, mirroring the bubble

Table 7. Heterogeneity test results of different types of cities

Variable	Innovative pilot city			Non-innovative pilot city		
	(1) lnhaf	(2) lnhc	(3) lninn	(4) lnhaf	(5) lnhc	(6) lninn
lnstd	0.095*** (6.80)	–0.028 (–1.53)	–0.044*** (–6.84)	0.047*** (6.49)	0.015 (1.17)	–0.032*** (–5.52)
lnhaf		–0.067* (–1.71)	–0.011 (–0.85)		–0.057* (–1.85)	0.019 (1.34)
lnhc			0.066*** (6.37)			0.054*** (6.50)
lnpgdp	–0.080** (–2.05)	0.169*** (3.30)	0.231*** (13.12)	0.061** (2.15)	0.234*** (4.81)	0.468*** (20.81)
lnfin	0.065 (1.23)	0.026 (0.38)	0.096*** (4.06)	0.039 (1.49)	0.150*** (3.33)	0.151*** (7.31)
lnind	0.010 (0.26)	–0.046 (–0.92)	0.015 (0.88)	0.003 (0.15)	0.042 (1.37)	–0.009 (–0.65)
lnurb	–0.085* (–1.93)	0.171*** (2.97)	0.231*** (11.69)	0.012 (0.52)	–0.027 (–0.65)	0.081*** (4.32)
lnopen	–0.031** (–2.15)	0.001 (0.04)	0.047*** (7.22)	0.025*** (4.03)	–0.023** (–2.15)	0.020*** (4.03)
lngov	0.099** (2.05)	0.049 (0.78)	0.124*** (5.74)	0.105*** (4.09)	–0.117*** (–2.64)	0.174*** (8.54)
lntec	–0.009 (–0.64)	–0.028 (–1.59)	–0.019*** (–3.14)	0.029*** (4.10)	–0.029** (–2.40)	–0.048*** (–8.74)
lninf	0.031** (2.35)	0.011 (0.64)	0.000 (0.07)	0.003 (0.30)	0.048*** (2.97)	0.002 (0.24)
Constant	3.204*** (5.54)	3.112*** (4.07)	–0.187 (–0.71)	1.419*** (3.95)	0.752 (1.21)	–2.266*** (–7.93)
Obs	1200	1200	1200	3344	3344	3344
Individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.191	0.445	0.836	0.103	0.454	0.845

Note: The data in the table was calculated using Stata. *, **, and *** are significant at the 10%, 5%, and 1% levels of significant horizontalness, respectively, with a *t*-values in parentheses.

warning in Lin et al. (2021), though this study quantifies the mediation contribution at 35%. Conversely, in non-innovative pilot cities, this pathway reverses to a positive effect, where the mechanism 'reduced housing affordability → enhanced human capital levels' promotes innovation. One possible interpretation is that, under conditions of relatively low baseline housing prices and innovation capacity, moderate supply–demand pressures may coincide with periods of accelerated urban development, during which innovation activities expand alongside infrastructure upgrading and industrial restructuring. Nevertheless, this interpretation remains exploratory rather than conclusive, as alternative explanations—such as rapid catch-up growth, omitted institutional variables, or policy-driven resource reallocation—cannot be fully ruled out.

This directional reversal in heterogeneity not only deepens our understanding of the housing market's non-linear impact on innovation but also offers policy implications: for innovative cities, strengthening housing security is essential to break the crowding-out cycle; for non-innovative cities, leveraging supply-demand pressures to 'leverage' human capital aggregation can drive gradient development. These insights expand the application boundaries of the chain framework, providing targeted intervention pathways for China's new urbanization.

Table 8 presents the test results of the mediation effect using the Bootstrap method for different city types. As the outcomes presented in this table demonstrate, it is evident that the 95% confidence interval for all mediation effects in both innovative pilot cities and non-innovative pilot cities did not encompass 0. Coupled with the significance of the coefficients mentioned earlier, this indicates the significance of the chain mediation effect. Specifically, in innovative pilot cities, the rising housing supply and demand ratio impede urban innovation levels through the chain intermediary mechanism of "weakening housing affordability → inhibiting human capital level". Conversely, in non-innovative pilot cities, we observe a statistically positive chained mediation effect. However, this finding should be interpreted with caution. Rather than indicating a universally applicable 'reverse mechanism,' the observed positive transmission may reflect a stage-dependent or context-specific phenomenon, potentially associated with low baseline innovation levels, transitional development

Table 8. Test results of the mediation effect of the Bootstrap method for different types of cities

City type	Type of intermediary effect	Intermediate effect size	95% confidence interval	
			LLCI	ULCI
Innovative pilot city	Chain mediation effect	–0.001* (–0.38)	–0.0003	–0.0002
	Population mediating effect	–0.009*** (–6.07)	–0.0112	–0.0058
Non-innovative pilot city	Chain mediation effect	0.001** (2.39)	0.0002	0.0012
	Population mediating effect	0.007*** (4.30)	0.0039	0.0103

Note: *, **, and *** represent significance at the 10%, 5%, and 1% significant levels, respectively, with *Z*-values in parentheses, and LLCI and ULCI represent the lowest and highest values of the 95% confidence interval, respectively.

phases, or concurrent policy interventions. At this stage, the empirical evidence allows us to document the existence of this pattern, but does not yet permit a definitive causal attribution to a 'forced innovation' mechanism".

Based on the findings above, it's evident that there's a notable divergence in outcomes between innovative pilot cities and their non-innovative counterparts. In innovative pilot cities, a rise in the housing supply-demand ratio tends to trigger fluctuations in housing prices. Given the generally elevated housing price levels in these cities, residents often struggle to afford high housing costs on limited incomes. This leads to a decline in housing affordability and, subsequently, a loss of urban human capital, which undermines the enhancement of urban innovation.

Conversely, in non-innovative pilot cities where economic development levels are comparatively lower, an increase in the housing supply-demand ratio also diminishes housing affordability. However, the decline in affordability translates to a higher ratio of housing prices to income. In cities with less advanced development, this higher ratio can actually stimulate regional economic growth. By fostering enhancements in urban infrastructure and facilitating the upgrading and diversification of industrial structures, these cities can cultivate a more conducive environment for innovation. This, in turn, attracts greater innovation investment and talent influx, thereby elevating the overall level of urban innovation.

5.3. Robustness checks

To verify the reliability of the empirical results, this study conducts robustness checks from three perspectives. First, the dependent variable is replaced. Specifically, the number of patent authorizations per 10,000 people is used as an alternative proxy for urban innovation. The corresponding results are reported in Tables 9–10. Second, to further eliminate potential interference from long-term, time-varying city-level trends, city-specific linear time trends are incorporated into the baseline two-way fixed effects model. Third, following the robustness testing strategy, different numbers of Bootstrap resampling iterations are employed. The mediation effects are re-estimated using 1,500 and 2,000 resamples, respectively, with the results presented in Table 11.

Table 9. Robustness test results: Replacing the dependent variable and adding city-specific linear time trends

Variables	Replacing the dependent variable			Adding city-specific linear time trends		
	(7) lnhaf	(8) lnhc	(9) lninn	(10) Lnhaf	(11) lnhc	(12) lninn
lnstd	0.052*** (8.16)	–0.004 (–0.38)	–0.033** (–2.31)	0.074*** (10.51)	–0.003 (–0.28)	–0.009** (–2.25)
lnhaf		–0.065*** (–2.59)	0.058* (1.70)		–0.071*** (–2.98)	0.020** (2.23)
lnhc			0.101*** (4.90)			0.021*** (3.52)
lnpgdp	0.004 (0.17)	0.291*** (7.83)	0.891*** (17.71)	–0.063** (–2.17)	0.200*** (4.54)	–0.005 (–0.34)
lnfin	0.034 (1.47)	0.155*** (4.10)	0.369*** (7.24)	0.040 (1.44)	0.051 (1.22)	0.013 (0.85)
lnind	–0.019 (–1.24)	0.029 (1.13)	0.038 (1.10)	–0.055*** (–3.27)	0.028 (1.11)	–0.069*** (–7.29)
lnurb	–0.008 (–0.36)	0.023 (0.67)	0.342*** (7.44)	0.004 (0.15)	–0.031 (–0.82)	–0.006 (–0.41)

End of Table 9

Variables	Replacing the dependent variable			Adding city-specific linear time trends		
	(7) lnhaf	(8) lnhc	(9) lninn	(10) Lnhaf	(11) lnhc	(12) lninn
lnopen	0.019*** (3.31)	–0.021** (–2.23)	0.037*** (2.99)	0.025*** (3.50)	–0.031*** (–2.95)	0.008** (2.08)
lngov	0.083*** (3.73)	–0.039 (–1.08)	0.174*** (3.55)	0.024 (0.98)	0.032 (0.88)	0.041*** (3.01)
lntec	0.026*** (4.36)	–0.050*** (–5.13)	0.159*** (12.01)	–0.019*** (–2.82)	0.010 (0.93)	–0.003 (–0.68)
lninf	0.007 (0.89)	0.050*** (3.92)	0.084*** (4.92)	0.013 (1.50)	0.026* (1.96)	–0.009* (–1.75)
Constant	2.233*** (7.56)	0.367 (0.75)	–14.773*** (–22.50)	–57.357*** (–3.56)	118.935*** (4.89)	–29.482*** (–3.27)
Obs.	4544	4544	4544	4,544	4,544	4,544
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City-specific linear trend	No	No	No	Yes	Yes	Yes
R^2	0.101	0.441	0.881	0.426	0.700	0.939

Notes: All statistics are calculated using Stata. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. *t*-values are reported in parentheses.

Table 10. Bootstrap mediation effect test results with the replaced dependent variable

Type of mediation effect	Mediation effect value	95% Confidence interval	
		LLCI	ULCI
Chained mediation effect	–0.001* (–1.46)	–0.0006	–0.0001
Total mediation effect	–0.014*** (–4.71)	–0.0205	–0.0083

Notes: *, and *** denote significance at the 10%, and 1% levels, respectively. *Z*-values are reported in parentheses. LLCI and ULCI represent the lower and upper bounds of the 95% confidence interval.

Table 11. Bootstrap mediation effect test results under different numbers of resampling iterations

Number of resamples	Type of mediation effect	Mediation effect value	95% Confidence interval	
			LLCI	ULCI
1500	Chained mediation effect	–0.001* (–1.88)	–0.0008	–0.0001
	Total mediation effect	–0.002*** (–2.91)	–0.0030	–0.0021
2000	Chained mediation effect	–0.001* (–1.91)	–0.0008	–0.0001
	Total mediation effect	–0.002*** (–2.90)	–0.0030	0.0021

Notes: *, and *** denote significance at the 10%, and 1% levels, respectively. *Z*-values are reported in parentheses. LLCI and ULCI represent the lower and upper bounds of the 95% confidence interval.

The results indicate that the significance and direction of the mediation effect coefficients remain consistent across all robustness checks. Therefore, the empirical findings of this study can be regarded as robust. In particular, an increase in the housing supply–demand ratio continues to suppress urban innovation through the chained mediation mechanism of "weakened housing affordability → reduced human capital levels".

6. Conclusions and policy implications

The main purpose of this study was to examine the mechanisms through which housing supply-demand dynamics and affordability affect urban innovation levels. The research explored the correlation between housing supply-demand and urban innovation through three mediating channels: housing affordability, human capital level, and the pathway "housing affordability → human capital level." The study commenced by selecting relevant variables and providing a data description for the intermediate variable, human capital level. The specific operational procedures of the stepwise method, its advantages and disadvantages, and the introduction of the Bootstrap method were subsequently analyzed.

Through a comprehensive literature review and development of a construction method based on a simple mediating effect model, the study constructed a chained multiple mediating effect model. The findings of empirical testing revealed that an increase in the housing supply-demand ratio suppresses urban innovation levels through the mediating channel "weakening housing affordability → inhibiting human capital level".

The study also explored innovation pilot cities and non-innovation pilot cities, finding a significant chained mediating effect in both cases. The findings revealed that, in innovation pilot cities, an increase in the housing supply-demand ratio inhibits urban innovation levels through the chained mediating channel "weakening housing affordability → weakening human capital level". In contrast, in non-innovation pilot cities, the housing supply-demand ratio's increase enhances urban innovation levels through the mediating channel "weakening housing affordability → increasing human capital level". Finally, after replacing relevant variables and altering the number of samples, the consistency of the robustness tests confirmed the accuracy of the empirical findings.

To promote the stable development of the housing market, improve the level of urban innovation and narrow the imbalance between regions, the following two policy recommendations are put forward in line with the research conclusions. Firstly, optimize the housing market policy: In underdeveloped cities, the government should formulate reasonable policies to stabilize the urban housing price and ensure the balance between supply and demand in the housing market. Housing supply should be based on the demand structure with the ability to pay, increase the effective supply, and ensure the rational return of the market demand structure. The government should strengthen demand guidance, regulation and management, and ensure it provides more housing opportunities while the market demand structure is reasonable.

Secondly, strengthen investment in urban innovation: For cities with low innovation levels, the government should increase investment in urban innovation and rationally allocate resources and funds, avoid the crowding out effect of the real estate industry on the capital and talent in the field of innovation, and provide a good innovation environment for innovative enterprises. Policies for talent subsidies and house purchase subsidies can be formulated to raise residents' income levels, especially in relatively undeveloped cities, to ensure talent is retained and attracted. In addition, the government can also seek to increase international trade, promote inter-regional exchanges, absorb innovative technologies from abroad and other regions, attract high-quality enterprises and resources to flow into the city, accelerate the upgrading and adjustment of urban industrial structure, rationally allocate inter-industrial resources, and promote comprehensive urban development. These policies will help smooth the development of the housing market, increase the level of urban innovation, and reduce regional imbalances. It is important to note that the observed 'reverse transmission' effect in non-innovative pilot cities should not be generalized beyond the specific developmental and institutional contexts examined in this study. Further micro-level data and dynamic identification strategies are required to determine whether this pattern reflects a transient growth-stage effect or a stable structural mechanism.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

This work was supported by Soft Science Research Program of Zhejiang Province (2026C15002), National Social Science Fund of China (23FJYB009), and China Postdoctoral Science Foundation (2026M790326).

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