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THE SPATIAL RELATIONSHIP BETWEEN INNOVATION CAPACITY AND HOUSING AFFORDABILITY IN CHINESE CITIES

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Abstract. With China's rapid urbanization, innovation capacity and housing affordability have become important factors affecting sustainable development. This paper aims to address this research gap by examining the spatial characteristics and correlation between the housing market and urban innovation capacity. With statistical analyses of the housing market and innovation indicators in China's major cities, there are following findings. Firstly, it is found that there are obvious spatial characteristics between urban innovation ability and housing affordability. Housing supply has a significantly positive effect on urban innovation, particularly in central regions. Similarly, housing demand also positively impacts urban innovation. The impact of the housing supply-demand ratio on urban innovation exhibits regional variation. Secondly, the impact of housing affordability on urban innovation levels exhibits a nuanced pattern, resembling an inverted "U" shape, particularly pronounced in the eastern region. When the housing price-to-income ratio remains below a critical threshold, its growth positively contributes to enhancing urban innovation levels. Thirdly, an increase in the housing supply-demand ratio adversely affects urban innovation levels through a mediated pathway. The housing supply-demand ratio serves as a vital metric indicating the housing market's stability.

Keywords: urban innovation ability, housing affordability, regional differences, housing market, spatial characteristics, spatial relationship.

JEL Classification: R31, O31, R11.

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1. Introduction

Amid the backdrop of rapid urbanization, the interplay between housing affordability and urban innovation capacity has increasingly garnered significant attention from both scholars and policymakers. However, significant controversy exists in the current theoretical literature regarding this relationship. On one hand, some scholars argue that housing affordability positively impacts innovation capacity. O'Neil (2018) contends that reasonable housing costs can attract high-quality talent to urban areas, thereby fostering technological innovation and economic growth. Similarly, Florida (2012) emphasizes that a livable urban environment is crucial for attracting creative industries and innovative talent, which is closely linked to housing affordability. On the other hand, some studies suggest that housing affordability may

adversely affect innovation capacity. High housing prices can force low-income populations to relocate away from city centers, thereby diminishing urban diversity and inclusiveness, which are recognized as important drivers of innovation (Wang et al., 2017a). Additionally, a constrained housing market may limit the entry and growth of businesses and entrepreneurs, ultimately stifling urban innovation vitality.

Existing research on the relationship between housing affordability and urban innovation capacity remains limited, particularly regarding spatial dynamics and nuanced interactions. While Wang et al. (2017b) explored the spatial spillover effects of urban technological innovation and Ye et al. (2018) examined the impact of floating populations on urban entrepreneurship, neither study addressed the interplay between housing markets and innovation capacity. This gap leaves the link between housing affordability and urban innovation ambiguous, calling for further investigation into their complex spatial interactions. In the context of China's rapid urbanization, housing, as a critical component of social infrastructure, not only directly impacts residents' quality of life but also plays a pivotal role in attracting and retaining talent. This talent aggregation, in turn, drives urban innovation and economic growth, making the relationship between housing affordability and innovation a key factor in achieving sustainable urban development.

Research has demonstrated that housing affordability is closely linked to residents' consumption capacity and entrepreneurial intentions, significantly affecting the economic vitality and competitiveness of cities. When housing burdens become excessive, it can lead to talent loss and stifle the momentum of entrepreneurship and innovation, creating a vicious cycle. Conversely, favorable housing conditions can help cultivate a conducive innovation ecosystem, enhancing the overall development potential of cities.

Despite the growing recognition of the importance of the housing market and urban innovation capabilities, existing literature reveals significant gaps in understanding their interaction and spatial characteristics, particularly regarding the specific mechanisms and pathways through which housing affordability influences urban innovation capabilities. Therefore, conducting in-depth research on the relationship between these two factors is essential, as it will not only illuminate their underlying dynamics but also provide theoretical support for the formulation of more targeted policies aimed at promoting sustainable urban development.

This paper aims to address the research gap by examining the spatial characteristics and correlations between housing markets and urban innovation capacity. It will first define and theorize these concepts at a macro level, exploring their significance and mechanisms in urban development. Next, through empirical analysis, it will investigate the spatial relationship between housing affordability and innovation capacity, uncovering distribution patterns and influencing factors across cities. Finally, informed by domestic and international experiences, the study will offer policy recommendations to support sustainable urban development in China.

To gain a deeper understanding of the complex relationship between housing markets and urban innovation capacity, this study will provide a conceptual definition and theoretical exposition of both elements at the macro level, exploring their roles and interactions within urban development. Building on this foundation, the research will employ empirical analysis to examine the spatial relationship between housing affordability and urban innovation capacity. The aim is to elucidate the interplay between housing market characteristics in different cities and levels of innovation capacity, while also identifying the underlying influencing factors. This research will not only establish a solid foundation for future research hypotheses but also offer valuable insights for policymakers seeking to promote sustainable urban development in China.

This paper is structured as follows: Section 2 reviews literature on urban innovation capacity and housing affordability. Section 3 outlines the theoretical framework, model, and data. Section 4 analyzes the spatial distribution of innovation capacity and housing affordability. Section 5 explores their relationship and empirical findings. Section 6 concludes with insights, policy recommendations, study limitations, and future research directions.

2. Literature review

2.1. The measurement and influencing factors of urban innovation ability

Hamidi et al. (2019) noted that innovation capability typically denotes the level of productivity or outcomes of innovative activities, a widely accepted definition. In this paper, urban innovation ability is construed as a city's scientific and technological, economic, and social innovation ability, reflecting a city's potential and actual performance. The index of city innovation ability can be categorized into the single core index method and comprehensive index system method. When employing a single index to gauge the innovation capability of a city, patent data is commonly selected (Komikado et al., 2021; Straccamore et al., 2023; Jin et al., 2022; Ma et al., 2023; Tan et al., 2022). He et al. (2022) revisited the influence and mechanism of housing prices on the quantity and quality of enterprise innovation from the perspective of innovation input and talent policy. Urban innovation encompasses various subjective and non-subjective factors, and a single index measurement may yield significant errors, thereby posing substantial limitations and failing to fully reflect urban innovation ability.

In contrast to the single index method, the comprehensive index system approach offers a more holistic reflection of a city's innovation capacity. Existing studies predominantly establish multi-index systems to measure urban innovation capability through various perspectives, including innovation carriers, innovation inputs, innovation activities, innovation outputs, innovation environments, and innovation performances (Sohn et al., 2016; He et al., 2017; Tang et al., 2024; Fan et al., 2021; Guo et al., 2023). From the perspective of innovation-driving forces, researchers have utilized indicators related to innovation-driven environmental factors, effect factors, resource factors, and principal factors to assess urban innovation capability (Zhang et al., 2023; Xu et al., 2022; Maryska & Wagner, 2015).

For instance, Zeng et al. (2023) employed social cooperation networks and multi-phase difference-in-differences (DID) methodologies to determine the transmission pathways and impacts of innovation city pilot policies on inter-urban collaborative innovation across 26 cities in the Yangtze River Delta from 2005 to 2020. Additionally, Yu and Cai (2021) analyzed patent data from the State Intellectual Property Office alongside newly registered enterprise data from the State Administration for Industry and Commerce to gauge urban innovation vitality.

In summary, the measurement of urban innovation capability, both domestically and internationally, incorporates both single index and comprehensive evaluation methodologies. Given the critical importance of data timeliness, this paper selects the Innovation and Entrepreneurship Index compiled by the Enterprise Big Data Research Center of Peking University as the primary measurement index for urban innovation capability to facilitate a more robust empirical analysis.

2.2. Housing affordability

Housing supply, viewed through the lenses of macro and microeconomics, encompasses the number of housing units available for purchase or rent within a given market. On the other

hand, housing demand pertains to the desire and ability of individuals or entities to acquire housing units. Demand is typically categorized into two main types: consumption and investment. These forms of demand are interrelated, with consumption demand often acting as a limiting factor on investment demand. The relationship between housing supply and demand denotes the proportional connection between the number of housing units supplied and the level of demand for housing within a specific time-frame and geographic area. This relationship reflects the equilibrium or imbalance between the two sides of the housing market.

The dynamics of supply and demand exert a significant influence on housing prices. When housing supply exceeds demand, an oversupply scenario occurs, leading to downward pressure on prices. Conversely, when demand outstrips supply, prices tend to rise. These price fluctuations directly impact the behavior and decision-making of consumers within the housing market.

2.2.1. Definition of housing affordability

Housing affordability is a crucial indicator for studying the housing market, encompassing a multitude of factors. It includes elements such as the inflation rate, population size, housing costs, loan interest rates, housing construction pace, investment scale, population income levels, and the overall development level of the economic system (Kleshcheva, 2021). However, due to differing research emphases, there is no universally accepted definition of housing affordability, both domestically and internationally. For instance, housing affordability has shifted away from understanding how housing spending contributes to poverty and disadvantage within the realm of social policy. Instead, it now primarily centers on the urban policy challenges associated with growing inequality in access to urban resources. Mulliner and Maliene (2011) suggested that housing affordability has traditionally been defined and assessed based on economic criteria, primarily the relationship between housing costs and income. Nonetheless, affordability is influenced not only by housing expenses and income but also by broader factors that impact a family's overall quality of life.

Stone (2010) posited that housing affordability refers to a family's ability to allocate funds to housing after accounting for essential non-housing living expenses. If the cost of obtaining satisfactory housing and a suitable living environment within the same housing market area surpasses the affordability threshold of these families, then they may be considered to be experiencing housing affordability challenges.

2.2.2. Index measurement of housing affordability

Currently, there are two primary methods for measuring housing affordability: the ratio method and the residual income method. The ratio method assesses housing affordability by examining the ratio of housing expenditure to household income. Common ratio methods utilized in contemporary research include the price-to-income ratio (PIR), rent-to-income ratio (RIR), housing cost-to-income ratio (CIR), monthly mortgage-to-income ratio (MIR), and the Housing Affordability Index (HAI), introduced by the National Association of Realtors (NAR) in 1981. Whitehead (1991) employed the ratio of housing expenditure to income to measure housing affordability. Liang et al. (2022) used the rent-to-income ratio to investigate the impact of home-sharing services provided by Airbnb on housing affordability in Hong Kong.

Výbošťok and Štefkovičová (2023) used the Housing Affordability Index to examine the link between housing affordability and quality of life among Bratislava's cross-border suburban residents. Dewita et al. (2018) emphasized that housing affordability is affected by factors such as housing type, transportation choices, and proximity to work and school. Chen et al.

(2024) highlighted the importance of both down payment and monthly payment affordability, noting the housing provident fund's role in improving affordability. Abeysinghe and Gu (2011) introduced an Affordability Index, defined as the ratio of lifetime earnings to house prices, to analyze trends in housing affordability across public and private sectors. Klypin and Vyunov (2018) calculated regional housing affordability indices to compare housing prices with average wages. Kleshcheva (2021) identified factors like inflation, population size, housing costs, loan interest rates, construction speed, investment scale, income levels, and economic development as key determinants of housing affordability.

The Residual Income Approach (RIA) assesses housing affordability by examining whether a family's residual income, after meeting housing consumption expenditure, is adequate to cover minimum social non-housing consumption expenses. If the residual income falls short of meeting these expenses, it suggests inadequate housing affordability; otherwise, the family is considered to have housing affordability (Stone, 2010). The fundamental concept of housing affordability revolves around how household income is distributed between housing consumption expenditure and other living expenses. There is a growing body of research, both domestically and internationally, utilizing the residual income method.

For instance, Cardoso (2019) compared the residual income method with the expenditure-to-income ratio, finding that most families face affordability challenges. Sari and Khurami (2023) examined housing affordability using ratios, residual income, and subjective methods. Mundt (2018) employed a comprehensive residual income approach to identify market segments and household types at risk of affordability issues. Revington and Townsend (2016) used the residual income approach to identify affordable rental housing for various household configurations. McConnell (2012) focused on residual income, studying whether residual income after housing expenditure was sufficient to meet non-housing demand. Coskun (2022) employed housing costs and multiple income variables, including residual income, to construct the social information housing cost-income (HCI) ratio.

Some scholars combine multiple methods to measure housing affordability. Hyejin and Minjung (2021) compared the rental income method with the residual income method to estimate the excessive housing cost burden among middle-aged and elderly tenants. Seo et al. (2022) examined rental housing affordability using the residual income method and the Housing Quality Act to verify determinants of affordability. Considering the scarcity of rent and housing expenditure data in this study, the paper opts to measure housing affordability using the ratio of the average sales price of residential commercial housing to the per capital disposable income of urban residents. A higher ratio indicates weaker housing affordability for residents, and vice versa.

2.3. Summary

In the research on measuring urban innovation capacity and its influencing factors, scholars have explored the productivity levels and outcomes of technological, economic, and social innovation from various perspectives. The methodologies employed primarily include single-indicator methods and comprehensive indicator systems (Tan et al., 2016; Fang et al., 2014; Lu & Li, 2010; Wang et al., 2017b).

In the domain of housing affordability research, scholars have examined the relationship between housing supply and demand from macroeconomic and microeconomic perspectives, as well as how these factors influence market behavior. Common approaches for measuring housing affordability include ratio methods and residual income methods (Zhou et al., 2010;

Wang & Li, 2022; Yin et al., 2023; Yu & Cai, 2021). However, these studies often fail to address the interaction and influence between housing affordability and urban innovation capacity.

Despite some progress in both areas, existing literature tends to treat them as independent domains, lacking systematic analysis. Moreover, empirical studies examining how housing affordability affects urban innovation capacity are relatively limited, particularly in comparative analyses across different cities and regions. This gap is further exacerbated by insufficient consideration of data timeliness and regional differences.

This paper addresses the research gap by exploring the impact of housing affordability on urban innovation capacity. The innovations of this study include: 1) developing an analytical framework to examine the interaction and influencing mechanisms between housing affordability and urban innovation capacity; 2) leveraging the latest data and empirical methods to enhance the timeliness and regional relevance of the research; 3) conducting comparative analyses across cities and regions to reveal the differentiated effects of housing affordability. This study provides empirical evidence for policymakers to promote sustainable urban development and enhance innovation capacity.

3. Theoretical modelling

3.1. Theoretical framework for analysing the impact of housing affordability on innovation

Modern urban development increasingly emphasizes innovation capability as a key driver of economic growth and urban competitiveness. This focus on urban innovation is grounded in the understanding that innovation not only propels technological advancement and industrial upgrading but also enhances overall quality of life and the attractiveness of cities. This, in turn, draws talent and investment. Numerous studies have demonstrated that urban innovation capability is influenced not only by technological progress and industrial structure but also closely tied to the social environment (Bhagat, 2004; Glaeser et al., 2005; Yazdani et al., 2016). Among the various social factors, housing issues play a crucial role in urban development, directly impacting residents' quality of life and their engagement in innovative activities (Gyourko et al., 2013; Ryczkowski, 2019; Gaidelys & Dailydka, 2016).

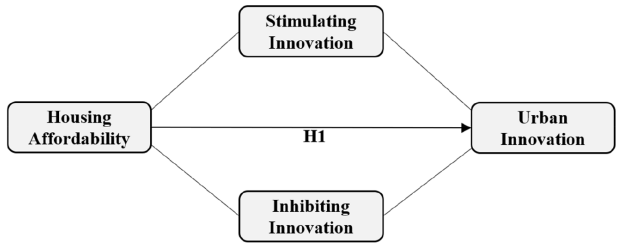

Figure 1. The framework for how housing affordability influences urban innovation

Housing affordability is not only related to individual economic conditions but also affects a city's human capital and social diversity. Research shows that high housing costs can hinder low-income groups from investing in education and entrepreneurship, thereby limiting the overall innovative potential of the city (Hsieh & Moretti, 2019; Nguyen et al., 2022). Mach (2019) highlights the impact of the global economic crisis on the real estate market, further

underscoring the connection between economic burdens and innovation capacity. Additionally, talent loss due to an imbalance in housing supply and demand may exacerbate social fragmentation and weaken urban economic vitality (Beracha et al., 2022; Bâra et al., 2023; Soy Temür et al., 2019).

Therefore, this study aims to explore the impact of housing affordability on urban innovation capacity. Figure 1 presents the theoretical framework of this paper on how housing affordability influences urban innovation. Housing supply (including both new and existing units) and housing demand are influenced by factors such as population growth, economic development, and social change (Glaeser et al., 2006), which collectively determine the supply-demand balance in the housing market. Market imbalances, such as housing shortages or excessively high prices, reduce housing affordability, increase economic pressure on residents, and may lead to talent loss, thereby inhibiting innovation. This phenomenon highlights the importance of achieving a balance between housing supply and demand. Only through reasonable housing policies and market regulation can a favorable environment for urban innovation be created.

Lower housing costs can attract highly skilled talent and innovative enterprises to cities, thereby enhancing urban innovation capacity. However, excessively low housing affordability may lead to inefficient land use and disorderly urban expansion, which can negatively impact the innovation environment (Hsieh & Moretti, 2019). A moderate level of housing affordability is crucial for maintaining social diversity within cities, as this diversity is considered an essential source of innovation (Ozdemir et al., 2023). Conversely, high housing costs may compel low-income groups to move away from city centers, resulting in a homogenized social structure that diminishes the vitality of innovation (Xu et al., 2025).

Government housing policies also play a significant role in regulating housing affordability (Yan & Feng, 2019). Thoughtful policy design can optimize the housing supply structure and improve housing quality, thereby creating a conducive social environment for innovative activities. However, excessive governmental intervention may lead to market distortions, disrupt the supply-demand balance in the housing market, and adversely affect urban innovation (Glaeser et al., 2005).

Empirical research on the relationship between housing affordability and urban innovation has been gradually increasing. Glaeser et al. (2001) highlight that the healthy development of the housing market is closely linked to urban innovation vitality. Furthermore, Bardoscia et al. (2025) indicates that the effectiveness of the housing market directly impacts entrepreneurial activities within cities. Case studies across multiple cities can provide clearer validation of the relationship between housing affordability and urban innovation capacity.

This study aims to investigate the impact of housing affordability on urban innovation capacity. Housing supply—including both new and existing housing quantity and quality—and housing demand are influenced by various factors, including population growth, economic development, and social change (Yan & Feng, 2019). These factors collectively determine the supply-demand balance in the housing market. When imbalances arise, particularly characterized by housing shortages or excessively high prices, housing affordability typically declines, increasing the economic burden on residents. This may ultimately lead to talent loss and inhibit urban innovation (Lin & Tsai, 2021). Additionally, research has established a positive relationship between social diversity and innovation capacity.

Achieving a balance in housing supply and demand is essential for promoting urban innovation. Strategies such as increasing housing supply, optimizing housing policies, improving housing quality, and reducing housing costs can effectively activate the housing market,

attract talent, and create a favorable urban environment for innovation (De Franco, 2023). Based on this theoretical framework, we propose the following hypothesis:

Hypothesis H1: *The impact of housing affordability on urban innovation levels has a nonlinear relationship*.

This hypothesis suggests that moderate housing payment pressure may spur innovation, as enhanced housing affordability allows residents to concentrate more on their career development and creativity, fostering active participation in innovative activities. However, when housing payment pressure surpasses a certain threshold, the economic burden on residents increases significantly, potentially leading to reduced investment in education, skill development, and entrepreneurship, thereby suppressing innovative potential.

Existing research supports this theoretical framework. Chen and Zhang (2016) found that high housing costs reduce residents' ability to invest in education and skill development, impacting innovation. Elevated housing prices limit household spending on culture, education, and technology. Dzemydaitė and Naruševičius (2023) linked technological growth efficiency to housing market dynamics, while Ryczkowski (2019) highlighted the influence of monetary policy on housing prices and the urban innovation environment. These studies collectively underscore the complex interplay between economic burdens and innovation capacity, validating the hypothesis.

Consequently, under conditions of moderate housing affordability, residents can sustain a high quality of life and actively engage in innovation activities. However, once housing payment pressure exceeds a critical threshold, residents may withdraw, opting to minimize risks and curtail innovative behavior. This dynamic relationship profoundly impacts a city's innovation capability and offers empirical insights for policymakers aiming to enhance housing policies and promote innovation, ultimately striving for a sustainable balance in the housing market.

3.2. Empirical modelling of the impact of housing affordability on urban innovativeness

Using panel data from 284 prefecture-level cities in China, a model was constructed to examine the influence of housing affordability on urban innovation levels. To enhance data comparability and mitigate the impact of heteroscedasticity, all variables were logarithmically transformed. Research indicates a nonlinear relationship: below a threshold, rising housing prices may boost innovation, but beyond it, they may hinder it.

Typically, testing for nonlinear relationships involves introducing the square term of the explanatory variable, assessing the significance of the coefficient of the quadratic term, and examining the different sign relationships between the coefficient of the linear and quadratic terms. Therefore, the current study incorporated the square term of housing affordability into the housing affordability model. The specific model that emerged is as follows:

$$\ln inn_{it} = \rho_0 + \rho_1 \ln haf_{it} + \rho_2 \left(\ln haf\right)_{it}^2 + \rho_3 C_{it} + \delta_{it} + \varphi_{it} + \varepsilon_{it}, \quad (1)$$

where i represents the city, t represents the year, $\ln inn_{it}$ represents the logarithmic form of the city's innovation level, $\ln haf_{it}$ represents the logarithmic form of housing affordability, and $(\ln haf)^2_{it}$ represents the square term of housing affordability. C_{it} represents the control variables (including the level of economic development, financial development, etc.), δ_{it} represents the individual effect, φ_{it} represents the time effect, ε_{it} represents the error term, and $\rho_{0\text{-}3}$ represents the coefficient.

3.3. Data description

This study utilizes data from 284 prefecture-level cities in China from 2005 to 2020. In addition to the Innovation and Entrepreneurship Index from Peking University's Enterprise Big Data Research Center, data were sourced from provincial statistical yearbooks, the China City Statistical Yearbook, the China Regional Economic Statistical Yearbook, and the EPS database. Due to the extensive geographic and temporal scope, some data were missing, which were addressed using linear interpolation. Table 1 offers a detailed description of each variable included in the analysis.

Table 1. Descriptive statistics of the variables

Variable Type	Variable	Symbol	Unit	Mean	Standard Deviation	Min	Max
Dependent variable	UIC	INN	/	70.121	21.074	7.527	100.000
Inde-pendent variable	Housing affordability	HAF	%	18.481	8.140	1.356	196.184
Control variable	Level of economic development	PGDP	yuan	42068.710	31509.950	2396.000	256877.000
	Financial development level	FIN	%	225.555	115.289	50.806	2130.150
	Industrial structure	IND	%	95.086	54.531	9.432	948.222
	Urbanization level	URB	%	51.127	16.948	11.410	100.000
	Degree of openness	OPEN	%	19.464	34.248	0.003	349.886
	Government intervention	GOV	%	17.982	10.185	4.262	148.516
	Scientific and technological level	TEC	‰	140.399	151.730	2.650	2068.350
	Infrastructure level	INF	Volume and parcel	5420.187	9000.206	134.818	440109.000
	Housing price	HP	Yuan per square meter	4509.355	3893.198	367.922	55719.580

Note: The data in the table are calculated using Stata software. The data come from the Enterprise Big Data Research Center of Peking University, China City Statistical Yearbook, China Regional Economic Statistical Yearbook, EPS database and statistical yearbooks of various provinces and cities.

4. Current analysis of urban innovation capacity and housing affordability

4.1. Analysis of the current status of urban innovation capability

4.1.1. Spatial distribution of urban innovation capability

Based on the measurement of urban innovation capacity indicators in Section 2.1, the current study adopted the Urban Innovation Capacity Index as the measure of urban innovation capacity. Focusing primarily on data from the years 2005, 2012, and 2020, this paper examines the Urban Innovation Capacity Index and its growth rate from 2005 to 2020, as depicted in Figure 2.

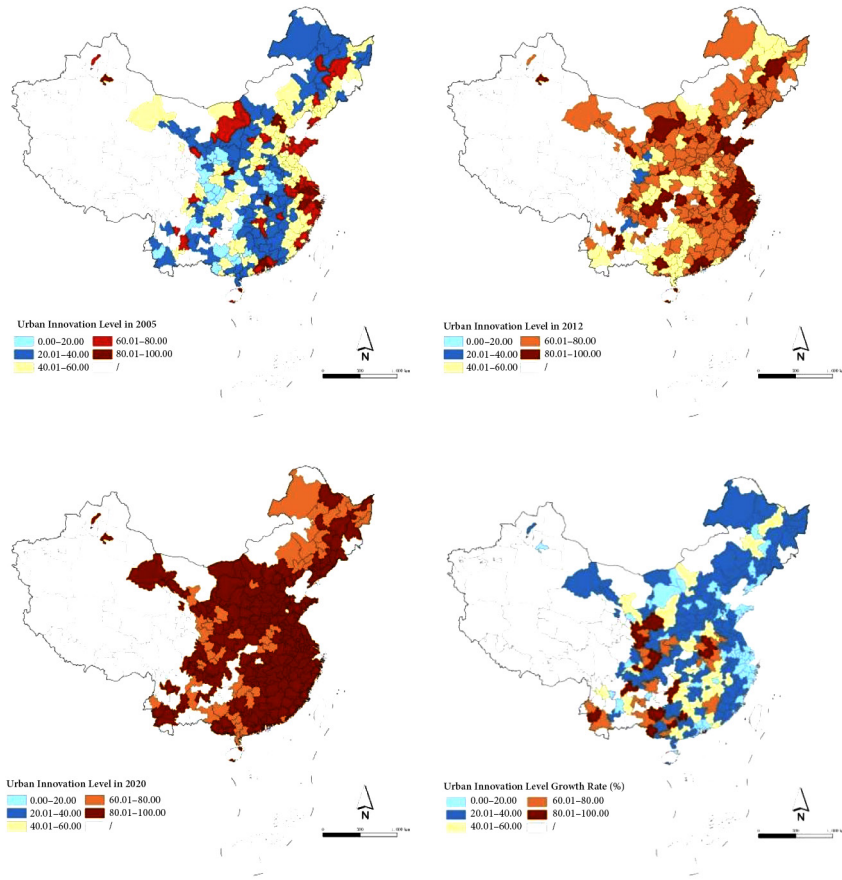

Figure 2. Distribution of urban innovation capacity and growth rate of urban innovation capacity, 2005, 2012 and 2020

In 2005, cities with high innovation capacity indices were primarily concentrated in key areas along the eastern coastal and central-western regions. Moving to 2012, there was a notable enhancement in innovation capacity in central-western cities, with over 80% of cities experiencing an increase, although the eastern and central-western regions still maintained

dominance. By 2020, the majority of cities exhibited innovation capacity indices exceeding 80, though disparities persisted, particularly between the eastern region and other areas. The growth rate in the central-western region generally outpaced that of the eastern region. In summary, key cities along the eastern coastal and central-western regions have consistently led in innovation capacity, while central-western cities have undergone rapid growth, thereby reducing regional disparities over time.

Cluster analysis of urban innovation capacity indices for the years 2005 and 2020 was performed. Figure 3 illustrates that in 2005, most cities in the eastern region exhibited a high-high clustering pattern, indicating both high urban innovation capacity indices and neighboring cities with high indices. In contrast, the central-western region showed a low-low clustering pattern, with both low urban innovation capacity indices and neighboring cities also demonstrating low indices. Some western cities (such as Chongqing) demonstrated a high-low clustering pattern, with high urban innovation capacity but low neighboring city capacity. Individual cities in Anhui, Hebei, and Guangxi predominantly exhibited a low-high clustering pattern, indicating low urban innovation capacity but high neighboring city capacity.

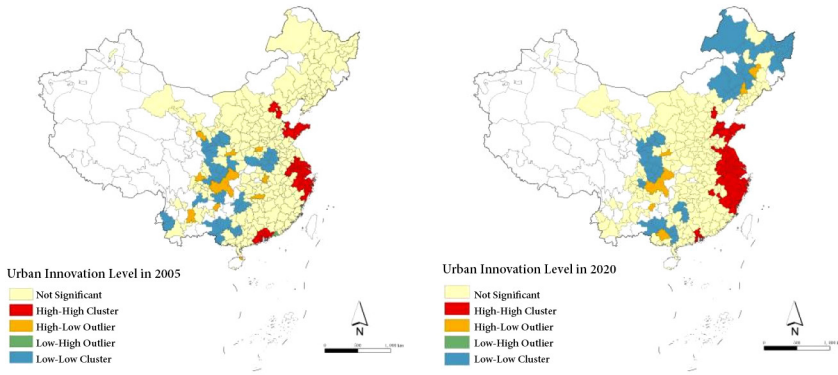

Figure 3. Cluster distribution of urban innovation capabilities in 2005 and 2020

Data from 2020 reveal an increase in the number of cities with high-high clustering, spreading towards the central region. Some cities in the central region transitioned from low-high clustering to high-high clustering, indicating a notable improvement in innovation capacity. Cities with low-low clustering were mainly located in the western and northeastern regions, with a decrease in the number of such cities in the west, indicating faster growth in innovation capacity in that region. Cities with high-low clustering were primarily distributed in the western and northeastern regions, with fewer low-high clustering cities in the central region. Overall, urban innovation capacity exhibits an east-high, west-low trend, but there is an enhancement in innovation capacity in the central-western cities, gradually reducing the gap with the eastern region.

Analyses of the urban innovation capacity indices for the years 2005 and 2020 were performed. The natural breaks classification method was utilized to categorize the hot and cold spots into five types: cold spots, sub-cold spots, transitional areas, sub-hot spots, and hot spots. As can be observed in Figure 4, in 2005, hot spots were mainly concentrated in the eastern region, particularly in the Yangtze River Delta area, while cold spots were primarily located in the central and western regions. Most cities in the eastern region belonged to the

sub-hot spot category, whereas sub-cold spots were predominantly distributed in the central and western regions, as well as the northeastern region.

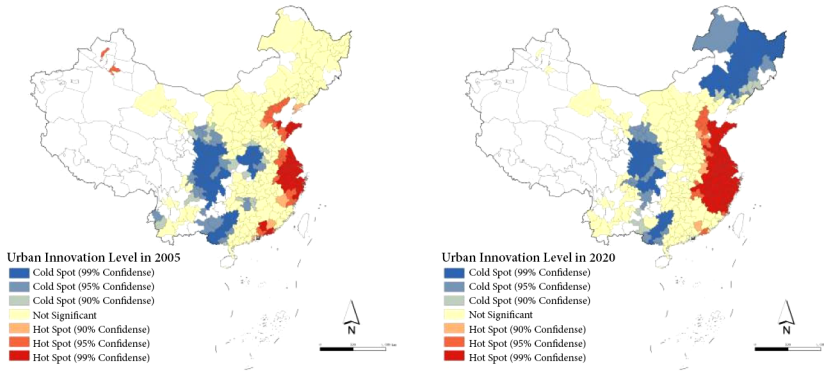

Figure 4. Cold and hot spots analysis of urban innovative capacity in 2005 and 2020

By 2020, there was an increase in the number of cities categorized as hot spots and sub-hot spots, gradually spreading towards the central region. Cold spots were mainly found in the western and northeastern regions, with a decrease in the number of cities in the cold spots in the western region and an increase in the northeastern region. Sub-cold spots were predominantly distributed in the central and western regions, as well as the northeastern region. Overall, the distribution pattern of hot and cold spots among prefecture-level cities nationwide demonstrates a trend of being hot in the east and cold in the west, with the cold spot area gradually shrinking and the hot spot area expanding towards the central and western regions.

4.1.2. Regional differences in urban innovation capacity

The spatial distribution analysis above indicates that the innovation capacity index of most cities showed a growth trend from 2005 to 2020, particularly with significant growth in central and western cities. However, disparities between the eastern and western, as well as the northern and southern regions, persist. This paper conducts a detailed data analysis of the regional differences in innovation capacity among cities nationwide, as well as in the eastern, central, western, and northeastern regions. It calculates the average values and growth rates of city innovation capacity for each region from 2005 to 2020, as shown in Figure 5.

The innovation capacity of cities across regions shows an overall upward trend with similar growth patterns. Growth was slow from 2005 to 2008 but accelerated thereafter. The central and western regions experienced the highest growth rates at 124.83% and 128.30%, respectively, while the eastern region had the lowest at 57.05%, followed by the northeastern region at 82.65%. Although cities in the eastern region maintain higher innovation capacity than the national average and other regions, the central, western, and northeastern regions have similar levels, all below the national average. Notably, the gap between the eastern region and others is gradually narrowing.

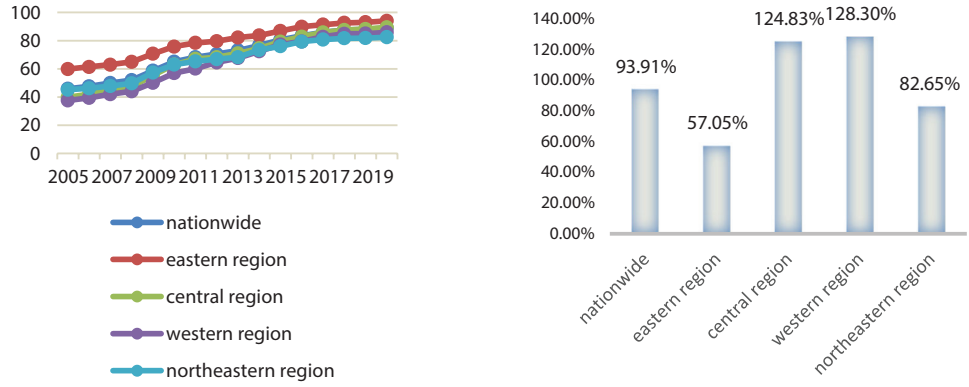

Figure 5. Average and growth rates of urban innovation capacity in different regions, 2005–2020

Spatially, urban innovation capability is growing overall, especially in the central and western regions. Eastern cities show high clustering, while the western region exhibits less clustering. Hot spots are concentrated in the east, with cold spots in the west gradually diminishing and hot spots spreading to central and western regions. While the eastern region leads in innovation capacity, the faster growth rates in other regions are steadily closing the gap.

4.2. Analysis of the current status of urban innovation capability

Based on the calculation method outlined in Chapter 2.2, the current study assessed housing affordability using the ratio of the selling price of residential commercial housing to the per capita disposable income of urban residents. The analyses examined the average housing affordability values for the years 2005, 2012, and 2020, along with the corresponding growth rates from 2005 to 2020. The results are depicted in Figure 6. The findings indicate that between 2005 and 2020, housing affordability values in most cities nationwide ranged predominantly between 10% and 20%. However, cities with housing affordability values exceeding 20% have increased, primarily concentrated in key cities along the eastern coast and central and western regions, with only a few cities exhibiting housing affordability values surpassing 30%.

Overall, there is a noticeable trend of housing affordability being higher in the east and lower in the west. The distribution of growth rates reveals that housing affordability in most cities has shown a positive increase. Cities with higher growth rates are primarily concentrated in specific areas within the central and western regions and the east, indicating rapid development in these cities' housing markets. However, this development has made it increasingly challenging for residents to afford rising housing prices, resulting in a decline in housing affordability. Conversely, housing affordability values in most cities within the central and western regions and the northeast exhibit a negative growth trend, reflecting an improvement in residents' income levels in these areas and an enhancement of their ability to afford housing.

To provide a clear understanding of the variations in housing affordability across different regions, the study progressed to calculate the average housing affordability and growth rates for each region from 2005 to 2020, as depicted in Figure 7.

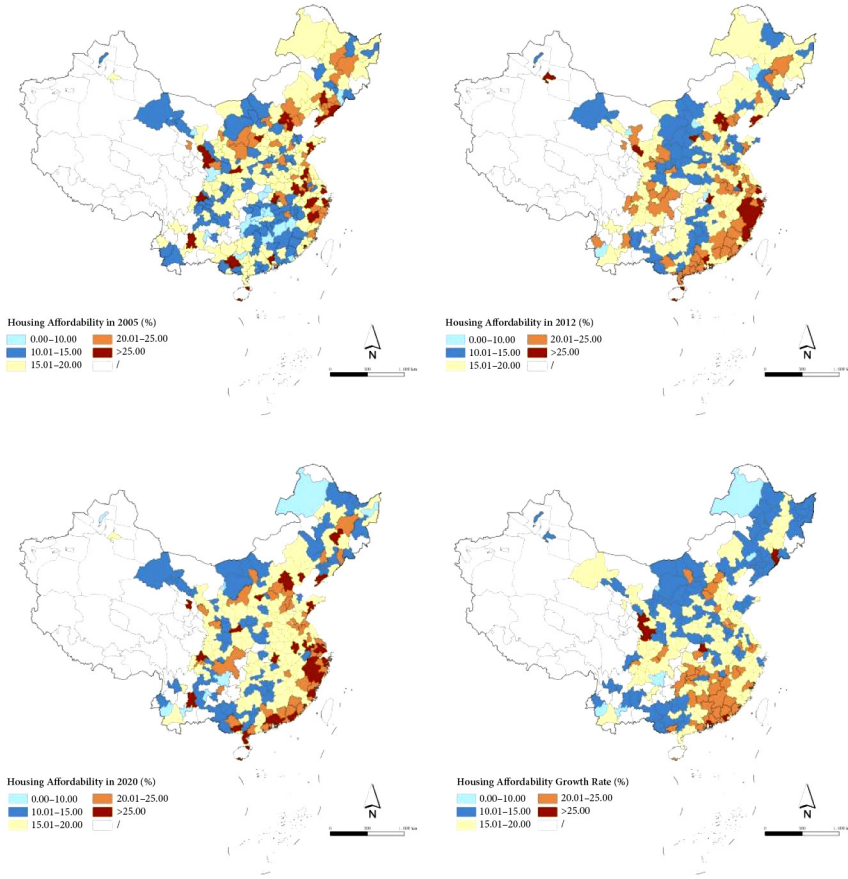

Figure 6. Distribution of housing affordability and housing affordability growth rates, 2005, 2012, 2020

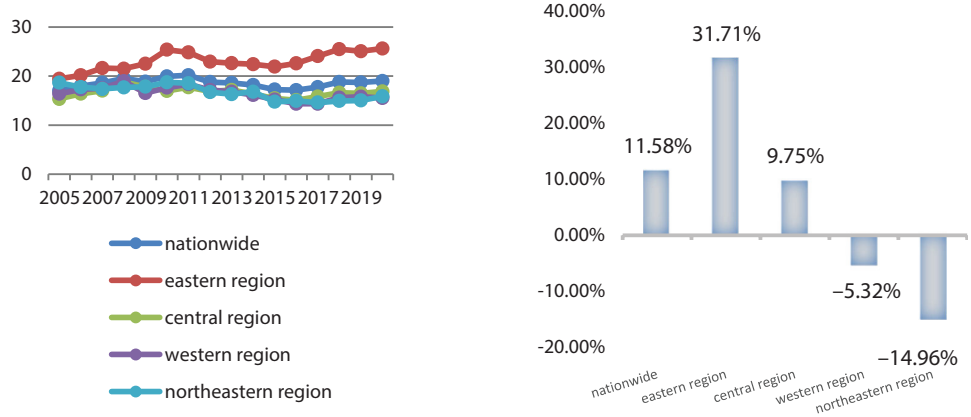

Figure 7. Average and growth rate of housing affordability in different regions, 2005–2020

As the chart clearly highlights, the overall growth in the housing price-to-income ratio remained sluggish across all regions, with the eastern region exhibiting the highest growth rate at 31.71%, while the northeast showed a negative growth trend. In terms of housing affordability, the overall level in the eastern region surpassed the national average and other regions, whereas the central, western, and northeastern regions exhibited relatively lower and similar overall levels of growth. These analytical findings correspond with those presented in Figure 6, indicating a gradual decline in housing affordability for residents in the eastern region, some instances of decline in certain cities within the central and western regions, some pockets of improvement, and a slight enhancement in housing affordability for the northeastern region.

In summary, the analyses of housing affordability revealed a relatively stable overall trend, with the urban housing price-to-income ratio being notably higher in the eastern coastal region and certain individual regions. The eastern region leads in terms of growth rate, while the central and western regions exhibited slower growth, and the Northeast region experienced negative growth, reflecting disparities in housing affordability among residents across different regions. The affordability of housing in the eastern region exhibited a slight decrease, with some cities in the central and western regions witnessing declines, but also instances of improvement and an overall increase in the Northeast region.

As the price-to-income ratio continues to rise, residents face increasing challenges in affording high housing prices. In such scenarios, the negative impact of housing affordability on urban innovation becomes increasingly pronounced. The escalating ratio of house price to income leads to a diversion of funds into the housing market, thereby reducing the availability of resources for innovation, ultimately hindering the enhancement of the innovation level (Wang et al., 2017a; Lu et al., 2019). Moreover, declining housing affordability prompts more talented individuals to leave cities due to payment constraints, thereby impeding talent concentration and stifling the advancement of innovation (Yang & Pan, 2020; Zhang, 2023).

5. Analysis of empirical results

5.1. The impact of housing supply and demand on China's urban innovation

According to the classification standards of the National Bureau of Statistics of China, the empirical data employed in the current study spanned the following categories and regions:

- Eastern region: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan provinces, totaling 86 prefecture-level cities with 1376 observations.
- Central region: Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan provinces, totaling 80 prefecture-level cities with 1280 observations.
- Western region: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shanxi, Gansu, Qinghai, Ningxia, and Xinjiang provinces, totaling 84 prefecture-level cities with 1344 observations.
- Northeastern region: Liaoning, Jilin, and Heilongjiang provinces, totaling 34 prefecture-level cities with 544 observations.

The results of the heterogeneity test in different regions are presented in Table 2. Firstly, the housing supply model results (models 1–4) showed a positive correlation between housing supply levels and urban innovation across all regions. This relationship was significant at the 1% level in the eastern, central, and western regions, and at the 5% level in the northeast.

Table 2. Outcomes of heterogeneity tests in different regions

Variable	Housing supply model				Housing demand model				Housing supply and demand ratio model			
	(1) Eastern Region	(2) Central Region	(3) Western Region	(4) North-east Region	(5) Eastern Region	(6) Central Region	(7) Western Region	(8) North-east Region	(9) Eastern Region	(10) Central Region	(11) Western Region	(12) North-east Region
ln*hs*	0.093*** (10.53)	0.109*** (10.94)	0.048*** (3.90)	0.023** (2.12)								
ln*hd*					0.106*** (12.09)	0.082*** (7.83)	0.071*** (5.56)	0.003 (0.23)				
ln*std*									–0.013 (–1.54)	–0.078*** (–8.59)	–0.061*** (–5.36)	0.024** (2.49)
ln*pgdp*	0.228*** (10.02)	0.365*** (9.95)	0.500*** (10.63)	0.232*** (5.11)	0.210*** (9.25)	0.368*** (9.73)	0.465*** (9.84)	0.253*** (5.67)	0.277*** (11.91)	0.393*** (10.60)	0.538*** (12.25)	0.249*** (5.66)
ln*fin*	0.006 (0.20)	0.191*** (5.72)	0.294*** (6.75)	0.011 (0.34)	0.034 (1.12)	0.199*** (5.85)	0.289*** (6.71)	0.023 (0.77)	0.006 (0.17)	0.194*** (5.70)	0.303*** (7.06)	0.037 (1.23)
ln*ind*	–0.011 (–0.57)	0.035 (1.34)	–0.016 (–0.65)	–0.017 (–0.74)	–0.018 (–0.89)	0.042 (1.56)	–0.027 (–1.09)	–0.020 (–0.83)	–0.024 (–1.16)	0.017 (0.63)	–0.019 (–0.76)	–0.021 (–0.89)
ln*urb*	0.169*** (6.96)	0.112*** (3.81)	0.111*** (3.14)	–0.029 (–0.71)	0.129*** (5.38)	0.090*** (3.00)	0.107*** (3.05)	–0.019 (–0.47)	0.146*** (5.56)	0.075** (2.53)	0.117*** (3.36)	–0.019 (–0.47)
ln*open*	0.041*** (4.30)	0.038*** (4.30)	0.008 (1.02)	0.003 (0.35)	0.041*** (4.31)	0.038*** (4.24)	0.007 (0.91)	0.003 (0.31)	0.030*** (3.03)	0.044*** (4.86)	0.006 (0.77)	0.003 (0.41)
ln*gov*	0.181*** (7.24)	0.239*** (6.04)	0.211*** (5.38)	0.216*** (6.98)	0.163*** (6.55)	0.247*** (6.06)	0.211*** (5.44)	0.218*** (7.02)	0.244*** (9.62)	0.246*** (6.09)	0.217*** (5.58)	0.199*** (6.28)
ln*tec*	–0.052*** (–7.30)	–0.076*** (–8.75)	–0.067*** (–5.60)	–0.043*** (–4.37)	–0.056*** (–7.93)	–0.072*** (–8.11)	–0.070*** (–5.86)	–0.044*** (–4.40)	–0.055*** (–7.46)	–0.063*** (–7.16)	–0.066*** (–5.55)	–0.046*** (–4.65)
ln*inf*	0.005 (0.65)	0.031*** (3.02)	0.034*** (2.60)	0.028* (1.84)	0.002 (0.24)	0.035*** (3.38)	0.038*** (2.88)	0.028* (1.81)	0.007 (0.89)	0.033*** (3.24)	0.037*** (2.82)	0.028* (1.81)
Constant	0.467 (1.58)	–2.122*** (–4.70)	–3.604*** (–6.10)	1.019* (1.70)	0.544* (1.86)	–2.310*** (–5.01)	–3.408*** (–5.87)	0.754 (1.28)	0.386 (1.24)	–1.880*** (–4.03)	–3.847*** (–6.83)	0.762 (1.30)
Obs	1376	1280	1344	544	1376	1280	1344	544	1376	1280	1344	544
Individual fixation effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.814	0.883	0.816	0.861	0.818	0.877	0.818	0.859	0.798	0.878	0.818	0.861

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

The impact was strongest in the central region, followed by the eastern region, and weaker in the western and northeastern regions.

Secondly, the housing demand model results (models 5–8) indicated a positive and significant effect of housing demand levels on urban innovation in the eastern, central, and western regions (1% level), but no significant impact in the northeast. The influence was greatest in the eastern region, followed by the central region, and lowest in the western region.

Finally, the housing supply-demand ratio model results (models 9–12) revealed no significant effect on urban innovation in the eastern region. However, the ratio had a significant negative impact in the central and western regions and a significant positive impact in the northeast. The negative effect was stronger in the central region than in the western region.

The empirical findings highlight significant regional disparities in development. The eastern region, with higher economic development and better resources, benefits from increased housing supply and demand, attracting talent and resources, boosting government innovation investment, and enhancing urban innovation. However, higher supply-demand ratios in the eastern, central, and western regions drive up housing prices, challenging innovation levels.

In contrast, the northeastern region's lower housing levels, combined with rising supply-demand ratios, promote economic development and improve innovation. Beyond housing factors, regional economic development and government intervention positively and significantly impact innovation across all regions, while technological levels show a significant negative effect. These findings emphasize the importance of economic development and government intervention in fostering urban innovation.

5.2. The impact of housing affordability on China's urban innovation

Based on the above data, regional heterogeneity tests were conducted for the eastern, central, western, and northeast regions, respectively. The results are shown in Table 3.

Table 3. Outcomes of heterogeneity tests in different regions

Variable	Housing Affordability Model			
	(1) Eastern Region	(2) Central Region	(3) Western Region	(4) Northeast Region
ln*haf*	1.341*** (10.05)	0.324** (2.50)	–0.109 (–1.15)	–0.934*** (–3.67)
$(\ln haf)^2$	–0.204*** (–9.74)	–0.043** (–2.05)	0.030* (1.71)	0.184*** (3.80)
ln*pgdp*	0.277*** (12.37)	0.425*** (11.22)	0.567*** (12.90)	0.232*** (5.25)
ln*fin*	0.031 (0.97)	0.200*** (5.75)	0.317*** (7.33)	0.021 (0.69)
ln*ind*	–0.020 (–1.01)	0.036 (1.30)	–0.002 (–0.07)	–0.025 (–1.09)
ln*urb*	0.141*** (5.66)	0.070** (2.28)	0.128*** (3.62)	–0.006 (–0.13)
ln*open*	0.026*** (2.71)	0.030*** (3.28)	0.006 (0.76)	–0.000 (–0.05)

End of Table 3

Variable	Housing Affordability Model			
	(1) Eastern Region	(2) Central Region	(3) Western Region	(4) Northeast Region
ln*gov*	0.208*** (8.46)	0.302*** (7.35)	0.219*** (5.60)	0.207*** (6.73)
ln*tec*	–0.048*** (–6.64)	–0.063*** (–7.00)	–0.068*** (–5.62)	–0.046*** (–4.63)
ln*inf*	0.007 (0.87)	0.046*** (4.37)	0.032** (2.42)	0.025 (1.65)
Constant	–1.861*** (–5.08)	–3.178*** (–6.36)	–4.285*** (–7.47)	2.164*** (3.13)
Obs	1376	1280	1344	544
Individual fixation effect	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes
R^2	0.812	0.872	0.814	0.864

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

The results of models 1–4 reveal that the coefficient of ln*haf* in the eastern region was 1.341, and the coefficient of $(\ln haf)^2$ was –0.204, both of which were significant at the 1% level, indicating that the housing affordability in the eastern region has a significant "inverted U-shaped" influence on the urban innovation level. The housing affordability value of the turning point was calculated as 26.76%. The coefficient of ln*haf* and $(\ln haf)^2$ in the central region was 0.324, and the coefficient of $(\ln haf)^2$ was –0.043, both of which were significant at the 5% level, indicating that the housing affordability in the central region also has a significant "inverted U-shaped" influence on the urban innovation level. The housing affordability value at the inflection point was 43.27%. The coefficient of ln*haf* in the western region was –0.109, which is not significant, and the coefficient of $(\ln haf)^2$ was 0.030, which is significant at the 10% level, indicating that the housing affordability in the western region has no "inverted U-shaped" influence on the urban innovation level. The coefficient of ln*haf* in Northeast China was –0.934, and that of $(\ln haf)^2$ was 0.184, both of which are significant at the 1% level, indicating that the housing affordability in Northeast China has a significant "U-shaped" influence on the urban innovation level. The housing affordability value at the turning point was determined to be 12.66%.

The above results indicate that the inflection point of the ratio of housing prices to income in the central region is higher than that in the eastern region, suggesting stronger housing affordability among urban residents in the eastern region. Despite higher housing prices in the eastern region, various factors, such as economic development, well-developed infrastructure, high-quality resources, and welfare policies, contribute to the overall higher income levels of urban residents, thus enhancing their housing affordability. In contrast, urban residents in the central region exhibit weaker housing affordability, mainly due to lower levels of economic development and overall income. Controlled variable results demonstrate that regional economic development and government intervention have a significantly positive impact on urban innovation levels across all four regions, while the influence of technology levels exhibits a significant negative effect in all four regions, and the impact of industrial structure on urban innovation levels is not significant across all four regions.

5.3. Robustness test

Taking into account the endogeneity issues within the model, it is possible that bidirectional effects exist between housing affordability and urban innovation levels. To assess this, we employed the two-stage least squares method (IV-2SLS) for robustness testing. We selected the lagged first and second periods of housing affordability, as well as the square of housing affordability, as instrumental variables.

Consistent with the full sample regression, we included both the core explanatory variables and control variables in the regression model for the robustness test, with the estimated results presented in Table 4.

The results indicate that, across the eastern, central, western, and northeastern regions, the sign and significance of the coefficients for the core explanatory variables have remained largely unchanged. These findings align closely with the estimates from the bidirectional fixed effects model, suggesting that the conclusions drawn earlier are robust.

Table 4. Robustness test results

Variable	Housing Affordability Model			
	(1) Eastern Region	(2) Central Region	(3) Western Region	(4) Northeast Region
ln*haf*	1.099*** (6.17)	0.561*** (4.34)	–0.087 (–0.78)	–0.826*** (–2.85)
(ln*haf*)^2	–0.169*** (–6.59)	–0.076*** (–4.12)	0.020 (0.89)	0.159*** (2.86)
ln*pgdp*	0.268*** (8.35)	0.327*** (9.26)	0.490*** (10.92)	0.218*** (4.51)
ln*fin*	0.087* (1.94)	0.196*** (4.00)	0.316*** (5.34)	0.074*** (2.65)
ln*ind*	–0.007 (–0.30)	–0.000 (–0.01)	–0.030 (–1.12)	–0.024 (–1.06)
ln*urb*	0.167*** (4.81)	0.087** (2.16)	0.150*** (3.02)	–0.001 (–0.02)
ln*open*	0.033*** (2.58)	0.029*** (3.26)	–0.001 (–0.12)	–0.004 (–0.43)
ln*gov*	0.170*** (2.84)	0.199*** (4.73)	0.183*** (4.34)	0.169*** (4.62)
ln*tec*	–0.018 (–1.59)	–0.034*** (–3.89)	–0.036*** (–3.25)	–0.026*** (–2.83)
ln*inf*	0.008 (1.10)	0.040*** (4.69)	0.022* (1.91)	0.009 (0.69)
Constant	–2.109*** (–3.90)	–2.607*** (–5.24)	–3.678*** (–5.55)	2.256*** (2.77)
Obs	1,204	1,120	1,176	476
Individual fixation effect	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes
R^2	0.885	0.890	0.871	0.898

Note: The data in the table was calculated using Stata. *, **, and *** are significant at the 10%, 5%, and 1% significance levels, respectively, with the z value in parentheses.

6. Conclusions

This study examined the impact of housing supply-demand dynamics and housing affordability on urban innovation levels from two perspectives. The initial step involved collecting and analyzing data from 284 prefecture-level cities across the years 2005 to 2020. This data encompassed information on housing supply-demand dynamics, housing affordability, and urban innovation levels, with the urban innovation index serving as the metric for measuring innovation levels. Subsequently, a two-way fixed effects approach was employed to construct empirical models aimed at evaluating the impacts of housing supply-demand dynamics and housing affordability on urban innovation levels. Finally, a chained multiple mediation model, "housing supply-demand dynamics → housing affordability → human capital level → urban innovation level" was established to further examine the mechanisms. The paper concludes with the following findings.

Firstly, the balance between housing supply and demand significantly impacts urban innovation, with increased housing supply positively influencing innovation, particularly in central regions and non-innovative pilot cities. This highlights the importance of a balanced housing market in fostering urban vitality. Secondly, housing affordability and urban innovation levels exhibit an inverted "U-shaped" relationship; in eastern regions, a moderate rise in the housing price-to-income ratio boosts innovation, while excessive increases suppress it, indicating varied impacts across regions. Additionally, housing supply-demand dynamics indirectly affect innovation by influencing affordability and human capital, with declines in affordability hindering innovation. This chain mediation model provides new insights into housing and innovation interactions. At the policy level, the study recommends stabilizing the housing supply-demand ratio, adopting talent attraction and housing subsidy policies in disadvantaged regions, and improving urban infrastructure and branding to attract enterprises and resources, enhancing innovation. However, limitations include reliance on new housing data, the focus on prefecture-level cities, and the lack of comparative analysis with other developing countries, suggesting future research directions.

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