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THE INTER-RELATIONSHIPS AMONG MOBILITY, HOUSING PRICES AND INNOVATION: EVIDENCE FROM CHINA'S CITIES

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Abstract. The existing literature contends that high housing prices are a negative factor inhibiting population mobility and urban innovation. This paper explores the interaction effect among population mobility, housing prices and urban innovation. Based on panel data from the Yangtze River Delta region from 2010 to 2019, we establish a simultaneous equation model (SEMs) to test the relationship between population mobility, housing prices, and urban innovation vitality. The empirical results show that (1) population mobility and housing prices are positively correlated; (2) urban innovation vitality has a significant and positive effect on housing prices; (3) population mobility and urban innovation vitality are also positively correlated.

Keywords: population mobility, housing prices, urban innovation, 3SLS, China.

Introduction

High housing prices have an inhibitory effect on innovation and migration. But in China, we have observed that cities with high housing prices are sought after by people, which are full of innovative vitality. These phenomena spark us to rethink the relationship between housing prices, migration and urban innovation. The economic development of Chinese cities has shifted from factor-driven to innovation-driven, and population mobility plays an important role in promoting urban innovation. Due to the unique household registration system and government-oriented urbanization, the economically developed cities on China's eastern coast have attracted a large number of floating population (Wang et al., 2017b). According to data from the seventh census of the China's National Bureau of Statistics in 2021, China's floating population is 375.82 million. Compared with the data of the sixth population census in 2010, the floating population increased by 69.73%. The agglomeration effect brought by population inflow can not only promote the transfer, diffusion and spillover of knowledge, information and technology, but also effectively promote the deepening of labor division and industrial upgrading (Storper & Scott, 2009; Cui & Chen, 2021). The scale of high-level floating population has become the main factor in improving urban innovation vitality (Bosetti et al., 2015; Lyu et al., 2019; Xia & Zhang, 2022; Wang et al., 2023a). In order to enhance innovation advantages, cities such as Beijing, Shanghai, Shenzhen, Guangzhou, Hangzhou have introduced various preferential policies to attract talents and promote population inflow.

At the same time, with the rapid development of the economy and the continuous growth of the population, housing prices in Chinese cities continue to rise. Since the establishment of a market-oriented housing system in 1998, the development of China's real estate industry has entered the fast lane, and housing prices in major cities are rising rapidly. The average price of residential commercial housing in China increased from 1,854 yuan/m^2 in 1998 to 10,396 yuan/m^2 meter in 2021, an increase of 5.61 times. Housing prices are affected by basic factors of supply and demand, such as urban population, wage income, land supply and construction costs, which are the main factors for house price increases (Wang & Zhang, 2014). Among them, population size and structure can directly affect changes in urban housing demand, and population decline and population aging will bring downward pressure

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on housing prices (Levin et al., 2009; Jäger & Schmidt, 2017; Choi & Jung, 2017; Gevorgyan, 2019; Ding, 2019). In addition, population mobility between cities will also affect housing prices, and larger population inflows will push up housing prices in large cities (Potepan, 1994; Tsai et al., 2018). Population mobility between urban and rural areas not only change the size and structure of urban population, which directly affect the demand of the real estate market, but also promote economic development and urbanization, which indirectly affect the development of the real estate industry (Wang et al., 2017b; Lin et al., 2018).

However, high housing prices are not conducive to population inflow, inhibit urban innovation, and harm the long-term sustainable socio-economic development. The movement of labor between cities is determined by wages, amenities, and housing costs. Housing costs can influence residents' housing preferences (Plantinga et al., 2013). High housing prices reduce the likelihood that individuals will choose the area, which has a dampening effect on population inflow (Potepan, 1994; Zhao & Fan, 2019). Also, high housing prices have a significant inhibitory effect on the mobility of high-skilled talents. The rise in housing prices increases the loss of high-skilled talents, resulting in the outflow of human capital, thereby inhibiting urban innovation (Chen et al., 2019; Yang & Pan, 2020b; Zhou et al., 2023). What's more, high housing prices will lead to a crowding-out effect. It makes money flow to real estate industry, crowds out the investment of R&D in enterprises, and inhibits urban innovation vitality (Lin et al., 2021).

In contrast, the core cities of the Yangtze River Delta, such as Shanghai, Nanjing, Hangzhou and Hefei with high housing prices attract many populations inflow every year. For example, in 2021, Shanghai's registered population was 14.93 million, but its permanent population was 24.89 million. The floating population was nearly 10 million. Housing prices and urban innovation in Yangtze River Delta cities have similar spatially distributed characteristics and there is a "high housing prices – high innovation (double high)" phenomenon (Teng et al., 2021). These are inconsistent with the inhibitory effect of high housing prices on population inflow and urban innovation shown in many research literatures. Based on these, we put forward research questions. (1) What is the relationship between population mobility and housing prices when considering the impact of urban innovation? (2) Is there a multilateral interaction among urban innovation, housing prices and population mobility? (3) In order to enhance innovation advantages, how can cities introduce housing policies and attract population inflow? To answer these questions, it is important to investigate the mutual influences of population mobility, house price and urban innovation vitality.

This paper establishes simultaneous equation models and analyzes the interactive relationship among population mobility, house price and urban innovation vitality based the panel data from 41 cities in the Yangtze River Delta from 2010 to 2019. Compared with existing literature, the main contributions are as follows. Firstly, the simultaneous equation model is established into an integrated analytical framework and examines the impact with considering the endogeneity. Secondly, this paper systematically analyzes the complex relationship between population mobility, housing price and urban innovation, which can expand the research content of urban innovation theory. Thirdly, this paper verifies the nonlinear influence of housing price on urban innovation and the interactive effect of population mobility and urban innovation. These can help policymakers to understand the driving impact of urban innovation more specifically, thereby improving the effectiveness of housing price regulation and population attraction policy design.

The remainder of this paper is organized as follows. The first section reviews the literature. The second section introduces the data variables and empirical models. The third section reports empirical results and discusses the results. The final section presents the conclusion.

1. Literature review

1.1. Population mobility and housing prices

Some existing studies have concluded that population mobility has a positive impact on housing prices. For example, Erol and Unal (2022) used data from 237 statistical areas in Australia from 2014 to 2019 and found that population mobility increases housing prices in immigrant-receiving areas, while immigration inflow has a significant positive impact on housing price changes in metropolitan areas. Moallemi and Melser (2020) found that if an area has an annual migrant inflow of 1%, housing prices will rise by around 0.9%. Degen and Fischer (2017) found that the overall immigration effect for single-family houses captures almost two-thirds of the total price increase.

Meanwhile, scholars have also discovered that rising housing prices have a negative effect on population mobility. Meng et al. (2023) used Tencent's population mobility data and found that the real estate boom has an indirect crowding-out effect on population mobility; in other words, the real estate boom negatively impacts the net income of renters, and this decrease in net income affects immigration decision-making. Kazakis (2019) used migration flows extracted from the SESTAT database to study the relationship between migration, innovation, and productivity among US college graduates, and found that high housing prices may reduce migration. Foote (2016), using the PSID dataset from 1984 to 2011, found that housing price declines lead to lower immigration among low-asset homeowners, but have no effect on the most leveraged homeowners, with housing lock-in effects impacting intrastate and interstate migrants. Modestino and Dennett (2013) examined data on interstate immigration in the United States from 2006 to 2009 and found that the lock-in effect of residential housing due to falling housing prices leads to a decrease in immigrant mobility, which in turn leads to a decrease in immigration. Rabe and Taylor (2012) combined UK panel data and other data sources from 1992 to 2007 and found that differences in housing price levels are an important determinant of household migration, with relatively high housing prices in potential destinations discouraging migration. Based on these prior studies, we might conclude that housing prices positively correlate with population mobility. Peng and Tsai (2019) used Taiwan's panel data from 1994 to 2016 to analyze the long-term and short-term effects of housing prices on population migration. The authors found that immigration and housing prices are cointegrated, and that the impact of housing prices on immigration is significantly positive in the long run and may be asymmetric in the short run.

Some scholars have already examined the relationship between the two, with varying results for various regions. d'Albis et al. (2019) established a PVAR model based on indicators such as population migration and housing prices in 22 French administrative regions. They revealed that rising housing prices inhibit population migration, but the impact of population migration on housing prices is insignificant. Tsai (2018) used data on housing prices in Taiwan from 1991 to 2016, and found that population migration and population density are the main factors affecting the diffusion effect of housing prices. The author verified that migration behavior is caused by housing price differences and the convergence of housing prices in different cities, with high housing price returns causing the residents in northern Taiwan to move to central Taiwan. Jeanty et al. (2010) used Michigan's census area-level data to study the relationship between migration and housing prices by building spatial joint cube equation models, wherein the results showed that neighborhood housing prices can rise if the population increases, and that neighborhoods are more likely to lose their population if their housing prices rise.

1.2. Housing prices and urban innovation vitality

Most scholars in this field find that high housing prices have an inhibitory effect on urban innovation vitality. Meanwhile, some scholars have determined that high housing prices have a crowding-out effect on innovative R&D funds, resulting in a decline in urban innovation vitality. Because the real estate industry is characterized by high investment returns and short capital payback periods, many entrepreneurs, including previously non-real-estate entrepreneurs, have shifted to investing in the real estate industry, leading to a rapid rise in housing prices and a distorted investment structure. It does not match credit funds and necessarily reduces investment in innovation and R&D for commercial or productive activities. Thus, high housing prices have a crowding-out effect on innovation and R&D funds, which in turn will inevitably weaken the city's innovative vitality (Lu et al., 2019; Chakraborty et al., 2018; Chen et al., 2015; Rong et al., 2016; Wang et al., 2017a; Wu et al., 2020). Talent is the cornerstone of innovation, and any innovative practice is dominated by human capital. Therefore, cultivating high-quality talents and improving urban innovation vitality is necessary for innovation (Caragliu & Del Bo, 2019; Li & Zhang, 2020), yet some scholars have found that high housing prices lead to a loss of urban human capital, thus weakening urban innovation vitality. For example, Lin et al. (2020) and Yang and Pan (2020a) found that urban housing costs have an important impact on the choice of labor employment locations. Rising housing prices push up the threshold of labor force survival, causing labor to flow to cities with relatively low housing prices, resulting in the loss of human capital in cities with high housing prices, and inhibiting the development of urban innovation vitality.

Some scholars have examined the impact of urban innovation vitality on housing prices as well as the mutual influence between the two. For example, Yao et al. (2020) found that urban innovation vitality increases housing market demand through human capital agglomeration, leading to rising housing prices. Later, Yu and Cai (2021) determined that an interaction exists between housing prices and urban innovation vitality. With the improvement of urban innovation vitality, housing prices rise accordingly, and thus the impact of housing prices on urban innovation vitality has an "inverted U-shape", wherein urban innovation vitality first rises and then falls as housing prices increase.

1.3. Population mobility and urban innovation vitality

Most of the existing literature focuses on the relationship between population mobility and urban innovation vitality, with the majority of scholars believing that increased population inflow can promote urban innovation vitality. Bonaventura et al. (2021) established the first labor mobility network in a metropolitan area in the United States by leveraging a publicly available dataset of entrepreneurial ecosystems, and found that large cities increase urban innovation by attracting talent inflow. By constructing a comprehensive dataset of 326 cities in China from 2000 to 2010, Yang and Pan (2020a) found that population decline leads to a decline in urban vitality, but the impact is not as severe as documented in the literature. Based on data from the sixth census of more than 270 cities in China, Lyu et al. (2019) found that innovative urbanization through high-skilled immigrant flow is an important driver of urban development in China, especially for eastern coastal cities and capital cities. Furthermore, the authors showed that the flow scale of high-skilled immigrants and the level of urban cultural diversity in China have a positive impact on urban innovation output. Fassio et al. (2019) examined the impact of skilled migration on European industrial innovation from 1994 to 2005 using labor force surveys in France and the United Kingdom and a micro-census in Germany, revealing that highly educated immigration had a positive impact on innovation, and its impact about one-third of the local technicians. Based on data from 35 large and medium-sized cities in China, Lan et al. (2020) found that increasing financial investment in social infrastructure can effectively improve urban vitality. Population inflow affects urban vitality through interaction with the social infrastructure. For instance, with the increase in the inflowing population, the positive impact of fiscal education expenditure on urban vitality will be enhanced, while the positive impact of fiscal medical and health expenditure on urban vitality will be suppressed. Biswas (2015) determined that high-skilled immigrants are mainly engaged in innovative activities, and thus their influx can improve urban innovation capabilities in developed and innovative countries; however, in less developed cities, high-skilled immigrants are used for imitation activities. Using data from 20 European countries from 1995 to 2008, Bosetti et al. (2015) found that the introduction of high-skilled talents is more likely to improve innovation capabilities. Using data from Australia, Jensen (2014) showed that immigration may actually stimulate innovation, thereby boosting job creation and productivity. Niebuhr (2006) explored the significance of labor cultural diversity on innovation output in various German regions, and found that differences in the knowledge and abilities of workers from different cultural backgrounds improves the performance of regional R&D departments, while diversity among high-quality employees has the greatest impact on innovation output.

Some scholars have studied the impact of urban innovation vitality on population mobility and the interaction between the two. For example, Kazakis (2019) found that a positive relationship exists between innovation and the inflow of high-skilled talents, whereby regions with higher innovation and productivity are more likely to attract inflows of human capital, and regions that attract more human capital tend to have higher innovation and productivity.

Based on the above review of the domestic and foreign literature, most of the existing research on population mobility and housing prices shows a positive impact of population inflow on housing prices. These rising local housing prices are inconducive to population inflow, and thus have a depressing effect on population mobility. Most studies on housing prices and urban innovation vitality still focus on the impact of housing prices on urban innovation vitality, with most studies showing an inhibitory effect. However, there are few studies on the impact of urban innovation vitality on housing prices or the interaction between the two. The extant research on the relationship between population mobility and urban innovation vitality mainly show that an increase in population inflow can enhance urban innovation vitality, yet there is less research on urban innovation vitality's effect on population mobility, nor has the mutual relationship between the two factors been thoroughly examined. We expect that an extremely close relationship exists between population mobility, housing prices, and urban innovation vitality. It must also be considered that in any relationship between the two, there will be certain differences in the results from different regions. Much prior research focused on the relationships between any two of the above three, yet relatively few studies have examined the relationship between all three. The innovative analysis framework of the three-element relationship permits the interactive analysis of the causal relationship between these three elements, which is the main contribution of this paper. Another contribution is this paper's use of data from the Yangtze River Delta region to test the causal relationship between the three using the three-stage least squares (3SLS) method.

2. Data and method

2.1. Variables and data

This paper selects population mobility, housing prices, and urban innovation vitality as the endogenous variables, and takes the control variables of regional economic development level, medical and health conditions, wage level, employment level, real estate development level, resident income level, green coverage rate, population density, urban rate, technological innovation level, foreign direct investment, cultural level, and talent level. The specific measures of each variable are as follows.

The endogenous variables are considered first. Indicators of population mobility (*pm*): Previous studies on population mobility, such as Lin et al. (2018) and Wang et al. (2020), expressed the floating population as the difference between the permanent population and the registered population; this paper refers to Lin et al. (2018), wherein the ratio of the net inflow population is used as an indicator of population mobility. The ratio of the net inflow population selected in this paper is calculated from the ratio of the net inflow population to the registered population, where the net inflow population is equal to the difference between the permanent population and the registered population. When the ratio is positive and the value is larger, it indicates that the region has more inflow compared with other regions; when the ratio is negative and the value is smaller, this indicates that the region has more outflow compared with other regions. Indicators of housing prices (*hp*): In the existing literature, most of the housing price calculation methods express the housing prices using the ratio of the sales of residential commercial housing to the sales area of commercial residential housing. Indicators of urban innovation vitality (*uiv*): Different scholars have discussed the measurement of urban innovation vitality from the perspectives of innovation environment, input and output. In view of the availability and understandability of the data, this paper measures urban innovation vitality as the number of patents granted per 10,000 people, and it is calculated based on the permanent population.

Next, we consider the control variables according to the Laurinavičius et al. (2022). The regional economic development level (*pgdp*) is measured by per capita GDP; the cultural level (*culture*) is measured by the library number

Table 1. Definitions and descriptive statistics of the variables

Type	Variables	Unit	Mean	Std. Dev.	Min	Max
Endogenous variables	*pm*	Percentage	2.98	21.24	–26.70	68.62
	hp	Chinese yuan per square kilometer	7603.38	4416.45	2470.79	32925.80
	uiv	Per ten thousand population	21.73	18.03	0.40	93.31
Control variables	*pgdp*	Chinese yuan	66012.05	37694.96	9068.00	199017.00
	income	Chinese yuan	33645.52	12330.88	12757.00	73615.00
	culture	One	5615146.00	11935000.00	200000.00	80630000.00
	emp	Percentage	75.70	12.94	44.81	97.3
	urban	Percentage	59.86	12.02	29.10	89.60
	wage	Chinese yuan	61572.94	20586.93	26275.00	160256.00
	hi	Ten thousand Chinese yuan	5529873.00	6815919.00	425300	42313800.00
	pfai	Chinese yuan	39088.95	19631.32	1700.13	124831.9
	tec	Ten thousand Chinese yuan	246861.20	512698.40	3553	4300000
	talent	Population	109607.80	158462.70	4994.00	877894.00

Notes: The data are from the Statistical Yearbooks of the respective provinces and cities, Eps database. To facilitate the analysis, the units of some of the financial data are converted.

of the prefecture-level cities; the income level (*income*) is measured by the per capita disposable income of the residents in each city; the wage level (*wage*) is measured by the average wage of the on-the-job workers in the prefecture-level cities; the real estate development level (*hi*) is measured by the real estate development investment in the prefecture-level cities. The urbanization rate (*urban*) is measured by the ratio of the urban permanent population to the total permanent population at the end of the year; the level of fixed asset investment (*pfai*) is measured by per capita fixed asset investment and calculated by the permanent population; the level of technological innovation (*tec*) is measured by the scientific and technological expenditures of the prefecture-level cities; the talent level is measured by the number of students in ordinary institutions of higher learning in the prefecture-level cities.

To further understand the data characteristics of each variable, we perform descriptive statistics on each variable, and the specific results are shown in Table 1.

2.2. Model construction

Much research has focused on the single equation model, but such a simple approach can only explain the relationship between one explained variable and multiple explanatory variables. There is, however, a need to study the relationship between multiple explained variables and multiple explanatory variables. Such a relationship should be examined using a simultaneous equation model (SEMs), which is a model involving multiple sets of equations established to distinguish the interactions between various variables on the basis of certain economic and social theories or assumptions. The explanatory variables are combined with multiple explanatory variables to form multiple single equations, which can then be combined to obtain an SEMs. Its variables comprise exogenous variables and endogenous variables. Endogenous variables refer to the variables whose values are determined by the model system, and they are the explained variables. Exogenous variables, on the other hand, have their values determined outside the model system. Variables determined by factors outside the system (including constant terms) are generally used as explanatory variables.

Because this paper studies the relationship between population mobility, housing prices, and urban innovation vitality, SEMs are used.

1. Population Mobility Model (*pm*)

Equation (1) shows the impact of housing prices (*hp*) and urban innovation vitality (*uiv*) on population mobility. We also consider the effects of other control variables on population mobility, such as the regional economic development level (*pgdp*) of a city, to see whether they will have an impact on population mobility in addition to the effects of the two endogenous variables. A city with a higher level of economic development may attract greater population inflows, and cities with lower economic development levels may have greater population outflows. Meanwhile, various influencing factors, such as income level (*income*), cultural level (*culture*), and employment level (*emp*), are considered control variables that may affect population mobility.

$$pm_{it} = \alpha_0 + \alpha_1 hp_{it} + \alpha_2 uiv_{it} + \alpha_3 pgdp_{it} + \alpha_4 income_{it} + \alpha_5 culture_{it} + \alpha_6 emp_{it} + \varepsilon_{it}, \quad (1)$$

where ε_{it} is the disturbance term, and *i* and *t* represent the city and time, respectively.

2. Housing Price Model (*hp*)

Equation (2) shows the impact of population mobility (*pm*) and urban innovation vitality (*uiv*) on housing prices. We also consider the impact of other control variables on housing prices, such as the city's real estate development level (*hi*). The lower the level of real estate development, the lower the housing prices in the city are likely to be. This also comprises factors such as the wage level of urban residents (*wage*), the urbanization rate (*urban*), and the level of investment in fixed assets (*pfai*), which will all have an impact on the housing price of the city.

$$hp_{it} = \beta_0 + \beta_1 pm_{it} + \beta_2 uiv_{it} + \beta_3 hi_{it} + \beta_4 wage_{it} + \beta_5 urban_{it} + \beta_6 pfai_{it} + \delta_{it}, \quad (2)$$

where δ_{it} is the disturbance term, while i and t represent the city and time, respectively.

3. Urban Innovation Vitality Model (*uiv*)

Equation (3) shows the effects of population mobility (*pm*) and housing prices (*hp*) on urban innovation vitality. We also consider the impact of other control variables on the city's innovation vitality, such as a city's technological innovation level (*tec*). This paper also considers the influence of control variables such as regional economic development level (*pgdp*) and talent level (*talent*).

$$uiv_{it} = \gamma_0 + \gamma_1 pm_{it} + \gamma_2 hp_{it} + \gamma_3 pgdp_{it} + \gamma_4 tec_{it} + \gamma_5 talent_{it} + \gamma_6 \left(hp\right)_{it}^2 + \theta_{it}, \quad (3)$$

where θ_{it} is the disturbance term, and i and t represent the city and time, respectively.

4. Simultaneous Equation Models

Thus, combining Equations (1), (2), and (3) produces the SEMs of population mobility, housing price, and urban innovation vitality:

$$\begin{cases} pm_{it} = \alpha_0 + \alpha_1 hp_{it} + \alpha_2 uiv_{it} + \alpha_3 pgdp_{it} + \\ \qquad \alpha_4 income_{it} + \alpha_5 culture_{it} + \alpha_6 emp_{it} + \varepsilon_{it} \\ hp_{it} = \beta_0 + \beta_1 pm_{it} + \beta_2 uiv_{it} + \beta_3 hi_{it} + \beta_4 wage_{it} + \\ \qquad \beta_5 urban_{it} + \beta_6 pfai_{it} + \delta_{it} \\ uiv_{it} = \gamma_0 + \gamma_1 pm_{it} + \gamma_2 hp_{it} + \gamma_3 pgdp_{it} + \gamma_4 tec_{it} + \\ \qquad \gamma_5 talent_{it} + \gamma_6 \left(hp\right)_{it}^2 + \theta_{it} \end{cases}. \quad (4)$$

3. Results and discussion

3.1. Unit root test

Panel data enhances the stability of the data to a certain extent. We need to perform a panel unit root test on each variable to prevent the false regression phenomenon. We hereby partially logarithmically treat the remaining variables, except for population mobility and the variables in percentages. Because the panel data selected in this paper is a short panel with large N and small T, two methods are used, namely the *HT* (*Harris-Tzavalis*) test and the *IPS* (*Im-Person-Shin*) test.

The unit root test results show that several variables in the original sequence are not stable; after the first-order difference, all variables are stable at the 5% level, wherein the regression analysis can be performed on the variables in this paper. Table 2 shows the results of the unit root test.

Table 2. Unit root test results

Variables	HT	IPS
pm	0.0250	0.0044
d.pm	0.0025	0.0000
lnhp	0.0080	0.0001
d.lnhp	0.0000	0.0000
lnuiv	0.3123	0.0006
d.lnuiv	0.0000	0.0000
lnpgdp	0.0000	0.0000
d.lnpgdp	0.0000	0.0000
lnculture	0.0000	0.0000
d.lnculture	0.0000	0.0000
lnincome	0.0000	0.0000
d.lnincome	0.0000	0.0000
emp	0.0098	0.0001
d.emp	0.0000	0.0000
urban	0.0009	0.0021
d.urban	0.0000	0.0000
lnwage	0.0036	0.0000
d.lnwage	0.0000	0.0000
lnhi	0.0000	0.0016
d.lnhi	0.0000	0.0000
lnpfai	0.1836	0.0000
d.lnpfai	0.0000	0.0000
lntec	0.0005	0.0088
d.lntec	0.0000	0.0000
lntalent	0.0211	0.0028
d.lntalent	0.0000	0.0000

Note: The numbers in the table indicate the p-values, and the gray parts indicate the test results after the first-order difference of the variables.

3.2. Analysis of the empirical results

After analyzing the established panel data SEMs, based on the identification of the order condition and rank condition of the SEMs, both equations are over-identified. There are two types of methods for estimating simultaneous equations, namely, the single equation estimation method and the system estimation method. First, the single equation estimation method aims to estimate each equation in the SEMs separately, including ordinary least squares (*OLS*), indirect least squares (*ILS*), two-stage least squares (2*SLS*) and generalized estimation of moments (*GMM*); the system estimation method aims to estimate the simultaneous equation model jointly as a system, mainly including the three-stage least squares method (3*SLS*) and system generalized moment estimation (*system GMM*).

Compared with other methods, 3SLS is a better estimation method for simultaneous equation models (SEMs). It can utilize all useful information and estimate all parameters in the model at the same time. It firstly estimates each equation by the 2SLS and then recovers the residuals of this first step to estimate the relationship between the error terms of different equations and uses the generalized least squares estimation (GLS) for estimate the overall model taking into account this information (Zellner & Theil, 1962). 3SLS not only solves the problems of endogeneity and consistency, but also considers the correlation among perturbation terms of different equations, which can avoid the deviation of estimation parameters. 3SLS estimation has also been successfully applied to analyze economic growth (Bakhsh et al., 2017; Kahouli, 2018), housing prices (Tsui et al., 2019), and foreign investment (Donaubauer et al., 2016; Singh, 2022).

Therefore, this paper adopts the system estimation method with higher efficiency. The SEMs were thus estimated by 3SLS. To reduce the influence of heteroscedasticity and autocorrelation on the regression results, this paper performs logarithmic processing on the remaining variables, except for the variables of population flow and those in percentages. Table 3 shows the overall test results.

In the equation of population mobility, the coefficient of *lnhp* is 16.59, which is significant at the 1% level, indicating that under the condition that other conditions remain unchanged, if the overall housing price in the Yangtze River Delta region increases by 1%, the ratio of the net inflow population will increase by 0.1659%, indicating that a rise in housing prices has a significant and positive impact on population mobility. The coefficient of *lnuiv is* 20.28, which is significant at the 1% level, indicating that for every 1% increase in urban innovation vitality, the ratio of net inflow population will increase by 0.2028%; the significantly positive impact of urban innovation vitality on population inflow.

These results shows that cities with high housing prices are equally attractive to the population, which is inconsistent with the findings of many research (Plantinga et al., 2013; Zhao & Fan, 2019; Kazakis, 2019). However, from the actual situation, most of China's population has migrated to the Pearl River Delta, Yangtze River Delta and Beijing-Tianjin-Hebei regions with developed economic levels, high housing prices and strong innovation vitality (Wang et al., 2017b). High housing prices do not necessarily lead to the loss of urban talent, and the elites still prefer superstar cities (Chen et al., 2019). This attraction may be because the cities with high housing prices have stronger innovation vitality, and more employment opportunities, better infrastructure and higher quality public services such as education and medical care (Lin & Wang, 2020; Cui et al., 2022).

In the equation of housing prices, the coefficient of *pm* is 0.009, which is significant at the 1% level, indicating that for every 1% increase in the ratio of net inflow population, housing prices will increase by 0.9%. This shows that, overall, the impact of population mobility on housing prices is significantly positive. The coefficient of *lnuiv* is 0.224, which is significant at the 1% level, indicating that for every 1% increase in urban innovation vitality, housing prices will increase by 0.224%; this suggests that the impact of urban innovation vitality on housing prices is significantly positive.

Table 3. Overall empirical test results

Variables	*pm*	*lnhp*	*lnuiv*
pm		0.009*** (4.15)	0.009*** (3.40)
lnhp	16.59*** (6.46)		18.90*** (3.90)
lnuiv	20.28*** (5.13)	0.224*** (6.05)	
lnpgdp	−19.12*** (−4.41)		0.753*** (6.58)
lnculture	2.050** (2.47)		
lnincome	−25.42*** (−6.32)		
emp	0.726*** (7.17)		
urban		−0.001 (−0.34)	
lnwage		0.693*** (12.77)	
lnhi		−0.003 (−0.13)	
lnpfai		−0.293*** (−10.13)	
$(lnhp)^2$			−1.025*** (−3.82)
lntec			0.074** (2.00)
lntalent			−0.015 (−0.45)
Constant	190.2*** (3.05)	3.721*** (6.61)	−93.00*** (−4.41)
N	410	410	410
R^2	0.4832	0.8095	0.8207

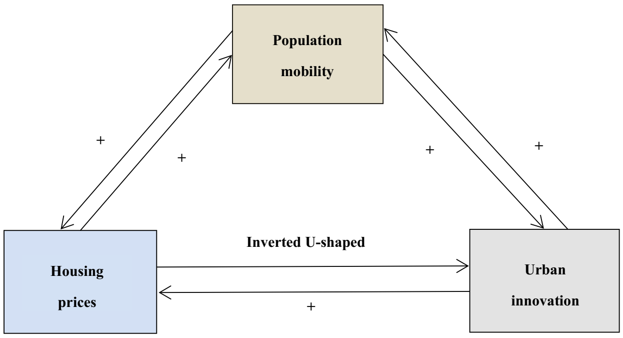
Note: *z* values are in parentheses; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

These results show that the increase of inflow population and innovation vitality can drive housing prices up, which is consistent with the findings of many research (Wang et al., 2017b; Moallemi & Melser, 2020; Yu & Cai, 2021; Erol & Unal, 2023). population mobility can not only directly affect the increase of urban housing demand, but also affect the level of urban economic development and urbanization, thus affecting the local real estate industry (Lin et al., 2018). innovation has a capitalization effect, and can increase the value of urban space. On the one hand, innovation can promote industrial restructuring and improve the quality of space and built environment, thereby having a positive impact on housing prices (Wu et al., 2021; Wang et al., 2023b). On the other hand, innovation can attract talents agglomeration to increase the demand for housing market, which can lead to higher housing prices (Yao et al., 2020).

In the equation of urban innovation vitality, the coefficient of *pm* is 0.009, which is significant at the 1% level, indicating that for every 1% increase in the ratio of net inflow of population, urban innovation vitality will increase by 0.9%, showing that the impact of population flow on urban innovation vitality is significantly positive. The coefficient of *lnhp* is 18.90 and the coefficient of $(lnhp)^2$ is –1.025, both of which are significant at the 1% level, indicating that the impact of housing prices on urban innovation vitality has an "inverted U-shape", i.e., the influence of housing prices on the innovation vitality of the city has an inflection point. When the housing price is lower than this inflection point, an increase in housing prices can promote the growth of urban innovation vitality. However, when the housing prices exceed this inflection point, any further increase will inhibit urban innovation vitality. According to the data, we can calculate that the housing price at the inflection point is 10,092.14 yuan/m^2.

The above results show that population mobility can significantly enhance urban innovation vitality. The impact of housing prices on urban innovation vitality is characterized by an inverted "U" shape. Population inflow can bring in more highly skilled talent, improve human capital in cities, and thus affect urban innovation vitality (Cui & Chen, 2021; Wang et al., 2023a). The agglomeration of urban population is conducive to the exchange of knowledge, promotes the deepening of labor division and industrial upgrading, and thus promotes enterprise innovation (Xia & Zhang, 2022; Cai et al., 2023). High housing prices can force enterprises to increase R&D expenditure to improve production efficiency to cope with the high costs caused by high housing prices. However, the continuous rise in housing prices will lead to crowding-out effect, which cause money flow to real estate industry. That may crowd out enterprise innovation money, and weaken urban innovation vitality (Yu & Cai, 2021; Lin et al., 2021).

Thus, the results of our overall test are as follows: (1) Considering the influence of urban innovation, population mobility and housing prices are significantly positively correlated with each other. Urban innovation can compensate for the weakening of the attractiveness of high housing prices on the population mobility. (2) There is an interactive relationship between housing prices and urban innovation. Urban innovation vitality has a significant positive impact on housing prices, and the impact of housing prices on urban innovation vitality is inverted "U" shape. When housing prices exceed the inflection point, the continuous rise in housing prices will have a negative impact on urban innovation vitality. (3) Considering the influence of housing prices, population mobility and urban innovation vitality are significantly positively correlated with each other. The increase of inflow population can increase human capital, which can promote urban innovation vitality. Cities with strong urban innovation vitality have more job opportunities and can attract more population. To facilitate understanding, we present the relationships between the three as a graph, shown in Figure 1.



Note: " + " indicates a significant positive effect.

Figure 1. The relationships of mobility, housing prices and innovation

3.3. Regional heterogeneity test

To further test the relationships among population mobility, housing prices, and urban innovation vitality in different regions of the Yangtze River Delta region, this paper conducts a regional heterogeneity test. Previous studies have classified cities according to population size. However, this paper takes the differences of the research objects into account, and it is not suitable for this study to use the classification standard of population size. Therefore, this paper adopts the classification criteria of first-, second-, third-, fourth- and fifth-tier cities for testing. The classification criteria are mainly based on the degree of commercial resource agglomeration, urban hub, urban people's activity, lifestyle diversity, and future plasticity. Due to the different classification results for different years, this paper uniformly uses the results of the city classification in 2019 for testing.

We divide the 41 prefecture-level cities in the Yangtze River Delta region into two categories. First-tier cities, new first-tier cities, and second-tier cities are grouped into one category, collectively referred to as first-tier cities; third-tier cities, fourth-tier cities, and fifth-tier cities are grouped into another category, collectively referred to as second-tier cities. According to the 2019 classification criteria, there are 16 first-tier cities and 25 second-tier cities. Table 4 shows the results of the regional heterogeneity test.

The results for the first-tier cities. The table shows that in the population mobility equation, the coefficient of *lnhp* is –9.484, which is significant at the 5% level, indicating that for every 1% increase in housing prices in first-tier cities, the floating population will decrease by 0.09484; the coefficient of *lnuiv* is 5.004, but it is insignificant, which indicates that urban innovation vitality has no significant impact on population mobility in first-tier cities. In the housing price equation, the coefficient of *pm* is –0.006, which is significant at the 1% level, indicating that for every 1% increase in population mobility, housing prices will drop by 0.6%; the coefficient of *lnuiv* is 0.414, which is significant at the 1% level, indicating that for every 1% increase in the level of urban innovation, housing prices will increase by 0.414%. In the urban innovation vitality

Table 4. Regional heterogeneity test results

Variables	First-tier cities			Second-tier cities		
	pm	*lnhp*	*lnuiv*	*pm*	*lnhp*	*lnuiv*
pm		−0.006*** (−2.89)	0.003 (1.16)		0.014*** (5.56)	−0.016*** (−2.93)
lnhp	−9.484** (−2.48)		15.05*** (4.00)	16.14*** (6.95)		−40.06*** (−3.80)
lnuiv	5.004 (0.83)	0.414*** (5.80)		−11.71*** (−4.25)	0.315*** (7.67)	
lnpgdp	−0.868 (−0.24)		0.721*** (6.97)	19.33*** (5.56)		1.033*** (8.47)
lnculture	10.94*** (6.54)			−2.728*** (−3.43)		
lnincome	−11.22 (−1.41)			−4.961 (−1.53)		
emp	2.016*** (8.53)			0.572*** (7.91)		
urban		0.013** (2.23)			−0.012*** (−4.97)	
lnwage		0.338*** (3.04)			0.531*** (7.65)	
lnhi		0.218*** (4.46)			−0.062** (−2.52)	
lnpfai		−0.356*** (−11.16)			−0.203*** (−5.72)	
$(lnhp)^2$			−0.789*** (−3.86)			2.362*** (3.92)
lntec			0.010 (0.13)			0.229*** (5.29)
lntalent			−0.176*** (−4.19)			0.180*** (4.18)
Constant	−128.9** (−2.08)	3.529*** (3.68)	−74.38*** (−4.28)	−277.1*** (−5.64)	5.847*** (7.83)	156.2*** (3.48)
N	160	160	160	250	250	250
R^2	0.8023	0.7528	0.6122	0.4146	0.5989	0.5333

Note: *t*-values are in parentheses; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

equation, the coefficient of *pm* is 0.003, but it is insignificant, indicating that population mobility has no significant impact on urban innovation vitality; the coefficient of *lnhp* is 15.05, the coefficient of $(lnhp)^2$ is −0.789, and both are significant at the 1% level, indicating that the impact of housing prices on urban innovation vitality is non-linear, and that there is an "inverted U-shaped" relationship between the two. This indicates that an inflection point exists in the impact of housing prices on urban innovation vitality. When the housing price is lower than this inflection point, any increase will have a significant positive effect on urban innovation vitality; when the housing price exceeds this inflection point, then any further increase will have a significant negative impact on urban innovation vitality. According to the calculation, the housing price at this inflection point is 13,868.69 yuan/m^2.

The empirical results for the second-tier cities. As can be seen from the table, in the population mobility equation, the coefficient of *lnhp* is 16.14, which is significant at the 1% level, indicating that for every 1% increase in housing prices, the floating population will increase by 0.1614; the coefficient of *lnuiv* is −11.71, which is significant at the 1% level, indicating that for every 1% increase in urban innovation vitality, the floating population will decrease by 0.1171%. In the housing price equation, the coefficient of *pm* is 0.014, which is significant at the 1% level, which means that for every 1% increase in population mobility, housing prices will increase by 1.4%; the coefficient of *lnuiv* is 0.315, which is significant at the 1% level, indicating that for every 1% increase in urban innovation vitality, housing prices will increase by 0.315%. In the urban innovation vitality equation, the coefficient of *pm* is −0.016, which is significant at the 1% level, indicating that for every 1% increase in population mobility, urban innovation vitality will decrease by 1.6%; the coefficient of *lnhp* is −40.06, $(lnhp)^2$ has a coefficient of 2.362, and both are significant at the 1% level, indicating that the impact of housing prices on urban innovation vitality is non-linear. Specifically, an inverted "U-shaped" relationship exists between the two, indicating that an inflection point exists in the impact of housing prices on the vitality of urban innovation. When the housing price exceeds this inflection point, any further increase has a significant negative effect on urban innovation vitality. According to the calculation, the housing price at this inflection point is 4817.94 yuan/m^2.

The results are extremely different between first-tier cities and second-tier cities, which produce almost opposite results. They also differ from the results of the overall test. Taken together, this reveals a significant regional heterogeneity in the Yangtze River Delta region.

3.4. Robustness test

This paper uses the urban innovation index to replace the number of patents granted per 10,000 people to measure urban innovation, and use the panel data of 41 cities in the Yangtze River Delta from 2007 to 2016 for robustness test.

Table 5. Results of robustness test

Variables	*pm*	*lnhp*	*lnuiv*
pm		0.01*** (5.26)	0.06*** (14.16)
lnhp	20.12*** (9.02)		16.15*** (3.63)
lnuiv	1.36* (1.92)	0.14*** (4.01)	
lnpgdp	7.49*** (4.88)		–0.73*** (–6.13)
lnculture	1.79*** (11.27)		
lnincome	–4.92 (–1.19)		
emp	0.23*** (5.82)		
urban		0.001 (0.53)	
lnwage		0.61*** (5.85)	
lnhi		–0.10** (–2.54)	
lnpfai		–0.21*** (–9.02)	
$(lnhp)^2$			–0.92*** (–3.64)
lntec			0.43*** (9.04)
lntalent			0.34*** (8.21)
Constant	–231.84*** (–7.22)	4.35*** (3.85)	–71.09*** (–3.80)
N	380	380	380
R^2	0.6963	0.7633	0.8127

Notes: *z* values are in parentheses; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

The data of urban innovation vitality coming from the "Report on City and Industrial Innovation in China" which was jointly completed by the Industrial Development Research Center of Fudan University. The report calculates the innovation index of 338 cities in China from 2001 to 2016 based on the value of patents. The results of robustness test are shown in Table 5. The results show that the signs of coefficients are not changed and are statistically significant. There are still interactive effects among population mobility, house price and urban innovation vitality.

Conclusions

With the increasing global social and economic competition, innovation has become the driving force for the development of a country or region. This paper studies the complex relationship between population mobility, housing price and urban innovation from the perspective of population agglomeration and housing cost. Based on the panel data of the Yangtze River Delta region from 2010 to 2019, this paper empirically analyzes the interaction between population mobility, housing price and urban innovation by using simultaneous equation model. The research findings are as follows.

First, considering the influence of urban innovation, there is a two-way causal effect between population mobility and housing prices. The increase of inflow population will promote the rise of housing prices, and cities with high housing prices still attract population. Second, the impact of housing prices on urban innovation presents an inverted "U" shaped, and when housing prices exceed inflection point, the rise of housing prices has a crowding-out effect on urban innovation. Urban innovation has a capitalization effect and has a significant positive impact on housing prices. Third, there is still a two-way causal relationship between population mobility and urban innovation vitality under the influence of housing prices. The inflow of population can enhance urban innovation vitality, and the improvement of urban innovation vitality can also attract more population inflow.

Based on the above research conclusion, this paper provides policy implication to enhance the competitive advantage of urban innovation and promote urban high-quality development.

First, local governments should establish personalized talent introduction policies and make full use of the innovation dividends brought by knowledge diversification. For example, they can use preferential policies such as housing subsidies to attract the inflow of highly educated and skilled population. At the same time, they should build a comprehensive housing security system to increase the supply of housing and satisfy the housing needs of inflow population. In addition, they may can increase fiscal expenditure on education, medical care, etc., improve the quality and efficiency of public services, and continuously attract population inflow, thereby enhancing urban innovation vitality and forming a virtuous circle.

Second, local governments should attach great importance to the impact of real estate investment and rapid housing price growth on the real industry, and establish a long-term mechanism for the healthy development of the real estate market. They can adopt policies such as purchase restrictions and price limits to stabilize house prices in a reasonable range. These can reduce the excessive concentration of resources in real estate and related industries, thereby increasing the investment of R&D in enterprises and further enhancing urban innovation vitality.

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Conflict of interests

The authors declare no conflict of interests.

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