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# Testing for stationary of housing prices in China: An examination using efficient unit root tests

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ABSTRACT

Changes in housing prices affect all aspects of production and life, and have always been a hot spot of social concern. This paper uses the sequence panel selection method (SPSM) to study the time series properties of housing prices in 100 cities in China from June 2010 to December 2022. It is found that there are large differences in the stationary of housing prices in first/second/third-tier cities. Using the SPSM test method, it is found that housing prices in first-tier cities are all non-stationary series, the samples of second- and third-tier cities can be significantly divided into stable housing prices and non-stable housing prices. After further using the Fourier function to approximate the structural mutation of the data, more second-tier cities show stable housing prices, while less third-tier cities show stable housing prices. These findings provide an important decision-making basis for the government to implement regulatory policies according to local conditions based on the differential characteristics of changes in housing prices.

## 1. Introduction

Real estate is an important part of China's wealth. Changes in housing prices affect the wealth of all Chinese residents and, by extension, all aspects of the macro economy, including consumption [1–5], labor supply [6–8], employment [9], Enterprise housing mortgage loan [10,11] and corporate investment [12,13]. This phenomenon is also found in developing countries such as Malaysia [14]. Therefore, the Chinese government always actively introduced policies to regulate the housing market, hoping to maintain the price stationary of the housing market. The regulation policies on housing prices can be roughly divided into two aspects, the demand side and the supply side. The demand side policies mainly include purchase restriction policy [15,16], transaction tax policy [17,18], property tax policy [19], and credit policy [20,21]. The supply side policies mainly include land supply regulation [22] and affordable housing construction [23].

The harm of the bursting of a housing bubble is enormous, and Chinese governments often regulate prices before there is a possibility of a bubble burst to avoid it. From this perspective, studying the stability of housing prices is more meaningful. The stationary of housing prices is an important indicator to test the effectiveness of policies, and has important economic and policy implications. If the housing price series is stable, the influence of external impact on prices is short, and housing prices will automatically return to the initial equilibrium state. Therefore, the government does not need to intervene too much on housing prices. If the housing price series is non-stationary, it suggests that external shocks will have a permanent influence on housing prices. Facing the rapid rise or fall of

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housing prices, it is very necessary for the government to implement intervening macro-control policies. Furthermore, housing prices may show different changes in different regions, and effective identification and differentiation will also help the government to adopt precise regulation of "one city, one policy" according to local conditions and improve the effect of regulation.

The aim of this paper is to analyze the stationary characteristics of housing prices in China at the provincial level. As the housing-construction industry varies across regions and development stages, it is crucial to understand the evolving path of house prices. Therefore, our dataset focuses on provincial-level house prices in China. To determine whether housing prices are stable or not, we use a range of unit-root tests, including standard first- and second-generation panel unit-root tests, as well as the sequence panel selection method (SPSM) unit-root test. Our approach enables us to accurately identify which regions in the panel have stable housing prices. This information is particularly important for policymakers adopting the "one city, one policy" regulation policy.

## 2. Literature review

Since Hamilton and Whiteman [24] and Hamilton [25] proposed the use of unit root tests to identify bubbles, it has become one of the main methods for studying asset price. The earliest studies on the stationary of housing prices are mainly concentrated in the United States and Britain, but no consensus has been reached so far. Meen and Peterson [26] used the standard unit root test and found that house price sequence in the whole UK followed the unit root process. Muñoz [27] used the quarterly data of 50 US states from 1975 to 1996 and the Dickey–Fuller generalized least squares (DF-GLS) test to find the unit root of housing price changes [28]. Meen [29] compared time series data of housing prices in the USA and the UK. Meen [30] conducted the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests on housing prices using the quarterly data of the US from 1976 to 1999 and the UK from 1969 to 1999, and found that housing prices in both countries followed the first-order differential stable process.

The inconsistency of unit root attribute of housing price is related to the shortcomings of traditional unit root test [31]. The subsequent literature expanded and supplemented the methods, one of which expanded from the unit root test of time series to the panel unit root test [26,32]. The general trend of the real estate market cannot effectively reflect the differences in the development of different regional markets. Prices range actually reflects the evolution of the real estate path, it adapts to different regions and different stages of development. Therefore, it always makes sense to test the house price series at the regional level. Traditional unit root tests do not take into account information across regions. As a result, traditional unit root tests do not account for information across regions. To increase the effectiveness of the unit root test, panel data began to be widely used [33–35]. However, panel test results do not provide information on the number of stationary process sequences when the null hypothesis is rejected. As they are not combined test of the null hypothesis. In this respect, Breuer et al. [36] claim that, similar to simple regression, each coefficient need not be non-zero when the F statistic rejection coefficient vector is equal to zero. Again, when the unit root primitive hypothesis is rejected, not all sequences are stationary. Based on the panel unit root test is a combination of all the members of the panel unit root test, not sure in the panel I (0) and I (1) the combination of series data. Further, Chortareas and Kapetanios [37] proposed the sequence panel selection method (SPSM), which divides the whole panel into a set of stationary series and a set of non-stationary series, and explicitly determines how many series and which series in the panel are stationary processes. Recent research has found regional differences in the stability of housing prices, even between very similar areas, such as in the United States [38–40], Tokyo [41–43], Australia [44,45].

The second extension is from the linear structure hypothesis to the nonlinear structure hypothesis, as many economic variables are nonlinear. Muellbauer and Murphy [46] pointed out that unstable transaction costs in the housing market can lead to nonlinearity. Seslen [47] argues that when there is less equity constraint, households exhibit forward-looking behavior and have a higher likelihood of trading during rising periods. However, this is not the case during the downturn in the housing market cycle, as households are less likely to transact when prices fall. Therefore, the housing price has a certain downward rigidity. As far as trading is concerned, loss aversion during a downturn is likely to reduce household liquidity. The real estate market is typically characterized by inconsistent market performance during periods of expansion and contraction [48]. In addition, Balcilar et al. [49] verified the existence of nonlinear behavior in South African housing prices, which is the same as our unity-root test procedure. Tests of assumed structural stability and linear adjustment do not provide evidence to support the stationarity of economic variables. Therefore, it is important and meaningful to include nonlinearity into the process of housing price data generation. The general method used to deal with nonlinear structures is to approximate the processing using dummy variables. It indicates a sharp and sudden change in trend or level. This approach is inconsistent with structural changes in the housing sector [50]. Leybourne et al., Balcilar et al. [49,51] developed the momentum threshold autoregressive (ST-MTAR) test for smooth transitions, which approximates abrupt changes as smooth and gradual processes. Lumsdaine and Papell, Lee and Strazicich [52,53] used ST-MTAR to test a number of long-term macroeconomic data in the United States and found that all economic sequences had significant structural mutations and showed a stable character after processing structural changes. The new test method developed by Becker et al., Enders and Lee [54,55] introduces Fourier transform to deal with structural changes of unknown form and unknown degree. Gallant, Becker et al., Pascalau and Enders and Lee [56–59] and others show that Fourier Approximation can capture the behavior of the unknown functions, even if the function itself is not a cycle. Recently, Canarella et al. [31] conducted linear and nonlinear unit root tests on the SandP Case-Shiller housing price index and found that the housing price is first-order single.

Similarly, many empirical studies have also used the unit root test method to examine the stationarity of housing prices in China. However, the conclusions drawn from these studies are not always consistent. There are studies that have found that housing prices in China are not stable and that there is a bubble [60–62], while other studies have found that housing prices in China are stable and that there is no bubble [63–65]. Other literature has found that the stability of housing prices in China varies by region [66–69].

Based on the above extension, this paper uses SPSM unit root test method based on Fourier function extension to study the stationary of housing prices in cities of different sizes in China. Economic development, socio-cultural factors and other heterogeneity across regions and income groups [70,71] should be taken into account when using city-level housing prices. Consider the nonlinearity that can occur as the housing market evolves across income levels and cities simultaneously. Some previous studies have pointed out that housing prices of cities of different levels in China are differentiated, but they are only empirical analysis, and the more advanced panel unit root test method is not adopted [72,73]. The panel unit root test method used in this paper can not only grasp the regional heterogeneity and cross-sectional correlation of the data, but also better deal with possible structural changes, which will provide more information on the changing characteristics of housing prices.

## 3. Methodology

Some time series contain unit roots and nonlinear characteristics. Traditional unit root tests provide limited information about mean-return trends in sequences. Therefore, many nonlinear tests have been applied, such as the nonlinear stationary test advanced by Kapetanios et al. [71] (KSS). KSS test is suitable for detection of ESTAR process. The main treatment is that the time series data can only be restored to the mean if it is far enough away from the mean. Therefore, the model is given by the following Equation (1):

$$\Delta \mathrm{HP}_t = \gamma HP_{t-1}\left\{1 - exp\left(-\theta HP_{t-1}^2\right)\right\} + v_t \tag{1}$$

In the equation, $\mathrm{HP}_t$ is housing price data. $\mathrm{HP}_{t-1}$ is a one-period lagged housing price data. $v_t$ is an independent and identically distributed (i.i.d.) error with a zero mean and constant variance. θ is the transition parameter of the ESTAR model and it governs the speed of transition. The null hypothesis is $\mathrm{HP}_t$ follows a linear unit-root process, and the alternative hypothesis is $\mathrm{HP}_t$ follows a nonlinear stationary exponential smooth transition autoregressive (ESTAR) process. The limitation of the above equation is related to the uncertainty of parameter γ under the original assumption. Kapetanios et al. [74] used first-order Taylor series approximation for $\{1 - exp(-\theta HP_{t-1}^2)\}$ under the null hypothesis θ = 0, and then used the following auxiliary regression to approximate Equation (2):

$$\Delta \mathrm{HP}_t = \zeta + \beta HP_{t-1}^3 + \sum_{i=1}^{k} b_i \Delta \mathrm{HP}_{t-1} + v_t, t = 1, 2, \ldots, T \tag{2}$$

In this framework, the null hypothesis and alternative hypothesis are expressed as β = 0 (non-stationarity) and β < 0 (nonlinear stationarity). Ucar and Omay [75] (UO test) extended Equation (3) to unit root test of nonlinear panel data, and the regression equation is as follows:

$$\Delta \mathrm{HP}_{i,t} = \gamma_i HP_{t-1}\left\{1 - exp\left(-\theta HP_{t-1}^2\right)\right\} + v_{i,t} \tag{3}$$

Furthermore, UO applied a first-order Taylor series approximation to Equation (4) around $\theta_i = 0$ for all i and obtained the following auxiliary regression:

$$\Delta \mathrm{HP}_{i,t} = \zeta_i + \beta_i HP_{i,t-1}^3 + \sum_{j=1}^{k} \theta_{i,j} \Delta \mathrm{HP}_{i,t-j} + v_{i,t} \tag{4}$$

Where $\beta_i = \theta_i \gamma_i$ and the hypotheses established for unit-root testing based on regression Equation (4) are as following Equation (5):

$$\mathrm{H0}: \beta_i = 0; \mathrm{for all i (linear non\text{-}stationarity)}$$

$$\mathrm{H1}: \beta_i < 0;\ \text{for some i};\ (\text{nonlinear stationarity}) \tag{5}$$

In addition, the KSS equations based on Fourier function extension are Equation (6):

$$\Delta \mathrm{HP}_{i,t} = \zeta_i + \delta_i HP_{i,t-1}^3 + \sum_{j=1}^{k} \theta_{i,j} \Delta \mathrm{HP}_{i,t-j} + a_{i,1} \sin\left(\frac{2\pi kt}{T}\right) + b_{i,1} \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_{i,t} \tag{6}$$

where t = 1, 2, …, T. The rationale for selecting $[\sin(\frac{2\pi kt}{T}), \cos(\frac{2\pi kt}{T})]$ is based on the fact that Fourier expressions are able to approximate absolutely integrable functions to any desired degree of precision. k represents the frequency selected for the approximation, $[a_i, b_j]'$ measures the amplitude and displacement of the frequency component. At least one frequency component must be present when a structural break occurs. The Fourier approximation can often capture the behavior of an unknown function, even if the function itself is not periodic [56–58,76]. When there is no a priori knowledge concerning the shape of breaks in data, a grid-search is performed to find the best frequency. Following Enders and Lee [76], we first set a maximum value of k = 5 and then run the test for k = 1, 2, 3, 4 and 5 to obtain an optimum value of k = k* for which the sum of squared residuals is minimized. We then use this optimum k* to conduct our panel tests. Understandably, k* varies across the cross-sectional units (between the housing markets in different cities).

Here, the SURKSS test of the Fourier function is combined with SPSM, and the specific test steps are as follows: a) The panel KSS test without/with the Fourier function of the sample data are carried out. When the null hypothesis of unit root cannot be rejected, the process stops, and all the sequences in the panel are determined to be non-stationary. When NULL is rejected, we proceed to next step; b) Remove series with the minimum KSS statistic because it has been identified as stationary; c) Return to step a for the remaining series, or stop the procedure if all of the series have been removed from the panel. d) The final result is to decompose the entire panel

**Table 1**
Cities studied.

| | |
|---|---|
| The first Tier Cities | Beijing, Shanghai, Guangzhou, Shenzhen |
| The Second Tier Cities | Tianjin, Chongqing, Hangzhou, Nanjing, Wuhan, Shenyang, Chengdu, Xian, Dalian, Qingdao, Ningbo, Suzhou, Changsha, Jinan, Xiamen, Harbin, Taiyuan, Zhengzhou, Hefei, Nanchang, Fuzhou |
| The Third Tier Cities[a] | Shijiazhuang, Tangshan, Qinhuangdao, Handan, Baoding, Langfang, Hengshui, Xining, Zibo, Dongying, Yantai, Weifang, Weihai, Rizhao, Dezhou, Liaocheng, Heze, Wuxi, Changzhou, Xuzhou, Lianyungang, Nantong, Huaian, Yancheng, Yangzhou, Zhenjiang, Taizhou, Suqian, Jiangyin, Changshu, Zhangjiagang, Kunshan, Wenzhou, Jiaxing, Huzhou, Shaoxing, Jinhua, Taizhou, Shandong, Quanzhou, Zhuhai, Shantou, Foshan, Zhongshan, Zhanjiang, Huizhou, Dongguan, Jiangmen, Haikou, Sanya, Wuhu, Maanshan, Ganzhou, Lyuoyang, Xinxiang, Yichang, Zhuzhou, Xiangtan, Mianyang, Guiyang, Kunming, Huhhot, Liuzhou, Guilin, Beihai, Nanning, Baotou, Eerduosi, Baoji, Lanzhou, Yinchuan, Wulumuqi, Anshan, Yingkou, Changchun, Jilin |

[a] The data of the six cities of Rizhao, Ordos, Baoji, Anshan, Yingkou, and Jilin were only updated to May 2020, so they were excluded from the sample, and the sample of the third-tier cities totaled 69.

**Table 2**
Summary statistics of housing prices.

| | All Cities | First-tier cities | Second-tier cities | Third-tier cities |
|---|---|---|---|---|
| **Obs** | 14914 | 604 | 3171 | 11139 |
| **Minimum** | 2787 | 12572 | 4929 | 2787 |
| **Average** | 9948.704 | 34251.23 | 11967.22 | 8056.303 |
| **Maximum** | 55150 | 55150 | 29976 | 28293 |
| **coefficient of variation** | 0.705505 | 0.380693 | 0.426981 | 0.439834 |
| **Standard Deviation** | 7122.318 | 13039.2 | 5109.78 | 3590.94 |
| **Skewness** | 18.10529 | 1.669729 | 5.687003 | 8.786733 |
| **kurtosis** | 3.436407 | 0.166125 | 1.591178 | 2.064322 |

into a set of mean-stationary sequences and a set of non-stationary sequences.

## 4. Data

This paper used the date monthly housing prices in 100 Chinese cities from June 2010 to December 2022, and the data comes from the Wind database which is not officially published. Wind is a leading provider of financial information services in China. Wind's data is frequently cited by authoritative Chinese and English media, research reports, and academic papers. The data for each city is the monthly data of 151 samples. All cities are divided into 4 first-tier cities, 21 s-tier cities and 75 third-tier cities according to their development levels (see in Table 1).

Table 2 shows the statistical characteristics of housing prices. The average housing price in the overall market is 9948.704 yuan/square meter, the average price in first-tier cities is 34251.23 yuan/square meter, the average price in second-tier cities is 11967.22 yuan/square meter, and the average price in third-tier cities is 8056.303 yuan/square meter square meters. The average price in first-tier cities is 4.22 times that of third-tier cities. Both the coefficient of variation and the variance of first-tier cities are larger than those of other cities, indicating that housing prices in first-tier cities fluctuate more. Skewness and kurtosis indicators show that housing prices in all cities are non-normally distributed.

## 5. Empirical results

### *5.1. Results of the first- and second-generation panel unit-root tests*

Table 3 presents the results of the four first-generation panel unit root tests. According to the test results of Levin et al. [32], the housing prices of the first, second and third tiers and the overall four samples are all stable. The test results of Im et al. [35] and Maddala and Kim [77] show that the housing prices of the first, second and third tiers and the overall four samples are all non-stationary. The results of Hadri [78] test show that housing prices in first- and second-tier cities are stable, while third-tier and overall housing prices are non-stable.

The housing prices between cities will mutually diffuse and affect each other [44,45,67,69,79,80], and the unit root test must also take into account this spatial correlation. Table 4 shows, the results of 5 s-generation panel unit root tests considering the cross-sectional correlation of panel data. The test results of Choi [81], Chang and Nonlinear [82], Bai and Ng [83] show that the housing prices of the first, second and third lines and the overall four samples are all non-stationary. The test results of Moon and Perron [26] show that the housing prices in the first-tier cities are non-stationary, while the housing prices in the second- and third-tier cities and the overall three samples are stable. The test results of Pesaran [84] show that housing prices in first- and third-tier cities are stable, while housing prices in second-tier and overall samples are non-stationary.

As mentioned above, both the first and second generation panel-based unit root tests are joint tests of the unit root of all members of the panel and thus cannot determine the mixture of I (0) and I (1) series in the panel setting. To determine how many regions in the panel and which ones support non-stationary processes, we proceed with SPSM combined with the panel KSS unit root test.

**Table 3**
The stationary results from the fist-generation panel unit-root test.

| | | | | | |
|---|---|---|---|---|---|
| Panel 3-1: First-Tier City Housing Prices | | | | | |
| Levin et al. [32] | $t_p^*$ | $\hat{p}$ | $t_p^{*B}$ | $t_p^{*C}$ | |
| | −4.882 | −0.015 | −4.834 | –4.843 | |
| | 0.000 | 0.000 | 0.000 | 0.000 | |
| Im et al. [35] | t − barNT | $W_{t,bar}$ | $Z_{t,bar}$ | t-$bar_{NT}^{DF}$ | $Z_{t,bar}^{DF}$ |
| | −2.335 | −1.874 | −0.554 | 0.046 | 3.682 |
| | | 0.030 | 0.290 | | 1.000 |
| Maddala and Kim [77] | $P_{MW}$ | $Z_{MW}$ | | | |
| | 10.297 | 0.574 | | | |
| | 0.245 | 0.283 | | | |
| Hadri [78] | Homo | Hetero | | | |
| | 86.0349 | 107.6923 | | | |
| | 0 | 0 | | | |
| Panel 3-2: Second-Tier City Housing Prices | | | | | |
| Levin et al. [32] | $t_p^*$ | $\hat{p}$ | $t_p^{*B}$ | $t_p^{*C}$ | |
| | −9.765 | −0.013 | −9.642 | −9.692 | |
| | 0.000 | 0.000 | 0.000 | 0.000 | |
| Im et al. [35] | t − barNT | $W_{t,bar}$ | $Z_{t,bar}$ | t-$bar_{NT}^{DF}$ | $Z_{t,bar}^{DF}$ |
| | −1.904 | −1.991 | 1.459 | −0.944 | 3.143 |
| | | 0.023 | 0.928 | | 0.999 |
| Maddala and Kim [77] | $P_{MW}$ | $Z_{MW}$ | | | |
| | 25.547 | −1.795 | | | |
| | 0.979 | 0.964 | | | |
| Hadri [78] | Homo | Hetero | | | |
| | 215.7328 | 266.5567 | | | |
| | 0 | 0 | | | |
| Panel 3-3: Third-Tier City Housing Prices | | | | | |
| Levin et al. [32] | $t_p^*$ | $\hat{p}$ | $t_p^{*B}$ | $t_p^{*C}$ | |
| | −20.245 | −0.020 | −19.548 | −19.686 | |
| | 0.000 | 0.000 | 0.000 | 0.000 | |
| Im et al. [35] | t − barNT | $W_{t,bar}$ | $Z_{t,bar}$ | t-$bar_{NT}^{DF}$ | $Z_{t,bar}^{DF}$ |
| | −2.173 | −6.207 | −0.488 | −1.052 | 4.655 |
| | | 0.000 | 0.313 | | 1.000 |
| Maddala and Kim [77] | $P_{MW}$ | $Z_{MW}$ | | | |
| | 117.024 | −1.263 | | | |
| | 0.902 | 0.897 | | | |
| Hadri [78] | Homo | Hetero | | | |
| | −6.3927 | −6.115 | | | |
| | 1.000 | 1.000 | | | |
| Panel 3–4: Housing prices for all cities | | | | | |
| Levin et al. [32] | $t_p^*$ | $\hat{p}$ | $t_p^{*B}$ | $t_p^{*C}$ | |
| | −22.752 | −0.017 | −22.112 | −22.252 | |
| | 0.000 | 0.000 | 0.000 | 0.000 | |
| Im et al. [35] | t − barNT | $W_{t,bar}$ | $Z_{t,bar}$ | t-$bar_{NT}^{DF}$ | $Z_{t,bar}^{DF}$ |
| | −2.120 | −6.645 | 0.145 | −0.981 | 6.233 |
| | | 0.000 | 0.558 | | 1.000 |
| Maddala and Kim [77] | $P_{MW}$ | $Z_{MW}$ | | | |
| | 152.868 | −1.812 | | | |
| | 0.972 | 0.965 | | | |
| Hadri [78] | Homo | Hetero | | | |
| | −7.3277 | −6.9349 | | | |
| | 1.000 | 1.000 | | | |

### *5.2. Results of the panel KSS test using the SPSM*

We report panel KSS unit root test results for first-tier, second-tier, third-tier and overall city housing prices in the left column of Tables 5–8. It also reports a series of panel KSS statistics and their bootstrap P-values on reduced panels, a single minimum KSS

**Table 4**
Second generation panel unit-root test.

| | | | | | |
|---|---|---|---|---|---|
| Panel 4-1: First-Tier City Housing Prices | | | | | |
| Chang and Nonlinear [82] | $IV - t^*$ | | | | |
| | 0.623 | — | — | — | — |
| | 0.733 | — | — | — | — |
| Choi [81] | $P_m$ | Z | $L^*$ | | |
| | 0.280 | −0.843 | −0.762 | | |
| | 0.390 | 0.200 | 0.223 | | |
| Bai and Ng [83] | $\hat{r}$ | $Z_{\hat{\hat{e}}}^{C}$ | $P_{\hat{\hat{e}}}^{C}$ | $MQ_c$ | $MQ_f$ |
| | 3.0 | −1.663 | 1.347 | 3.000 | 3.000 |
| | | 0.952 | 0.995 | | |
| Moon and Perron [26] | $t_a^*$ | $t_b^*$ | $\hat{\rho}_{pool}^{*}$ | $t_a^{*B}$ | $t_b^{*B}$ |
| | −1.056 | −0.668 | 0.992 | −0.961 | −0.622 |
| | 0.145 | 0.252 | | 0.168 | 0.267 |
| Pesaran [84] | $P^*$ | CIPS | $CIPS^*$ | | |
| | 7 | −2.270 | −2.270 | | |
| | | 0.070 | 0.070 | | |
| Panel 4-2: Second-Tier City Housing Prices | | | | | |
| Chang and Nonlinear [82] | $IV - t^*$ | | | | |
| | 1.772 | — | — | — | — |
| | 0.962 | — | — | — | — |
| Choi [81] | $P_m$ | Z | $L^*$ | | |
| | −0.186 | −0.707 | −0.677 | | |
| | 0.574 | 0.240 | 0.249 | | |
| Bai and Ng [83] | $\hat{r}$ | $Z_{\hat{\hat{e}}}^{C}$ | $P_{\hat{\hat{e}}}^{C}$ | $MQ_c$ | $MQ_f$ |
| | 2.0 | 0.005 | 42.046 | 2.000 | 2.000 |
| | | 0.498 | 0.469 | | |
| Moon and Perron [26] | $t_a^*$ | $t_b^*$ | $\hat{\rho}_{pool}^{*}$ | $t_a^{*B}$ | $t_b^{*B}$ |
| | −3.353 | −2.435 | 0.991 | −3.130 | −2.321 |
| | 0.000 | 0.007 | | 0.001 | 0.010 |
| Pesaran [84] | $P^*$ | CIPS | $CIPS^*$ | | |
| | 4 | −1.794 | −1.794 | | |
| | | 0.495 | 0.495 | | |
| Panel 4-3: Third-Tier City Housing Prices | | | | | |
| Chang and Nonlinear [82] | $IV - t^*$ | | | | |
| | 3.537 | — | — | — | — |
| | 1.000 | — | — | — | — |
| Choi [81] | $P_m$ | Z | $L^*$ | | |
| | 0.238 | −2.109 | −1.948 | | |
| | 0.406 | 0.017 | 0.026 | | |
| Bai and Ng [83] | $\hat{r}$ | $Z_{\hat{\hat{e}}}^{C}$ | $P_{\hat{\hat{e}}}^{C}$ | $MQ_c$ | $MQ_f$ |
| | 3.0 | −1.527 | 112.635 | 2.000 | 3.000 |
| | | 0.937 | 0.944 | | |
| Moon and Perron [26] | $t_a^*$ | $t_b^*$ | $\hat{\rho}_{pool}^{*}$ | $t_a^{*B}$ | $t_b^{*B}$ |
| | −12.104 | −7.078 | 0.978 | −11.482 | −6.895 |
| | 0.000 | 0.000 | | 0.000 | 0.000 |
| Pesaran [84] | $P^*$ | CIPS | $CIPS^*$ | | |
| | 6 | −2.102 | −2.102 | | |
| | | 0.050 | 0.050 | | |
| Panel 4-4: Housing Prices for All Cities | | | | | |
| Chang and Nonlinear [82] | $IV - t^*$ | | | | |
| | 3.996 | — | — | — | — |
| | 1.000 | — | — | — | — |
| Choi [81] | $P_m$ | Z | $L^*$ | | |
| | 0.174 | −2.315 | −2.147 | | |
| | 0.431 | 0.010 | 0.016 | | |
| Bai and Ng [83] | $\hat{r}$ | $Z_{\hat{\hat{e}}}^{C}$ | $P_{\hat{\hat{e}}}^{C}$ | $MQ_c$ | $MQ_f$ |
| | 3.0 | −2.687 | 135.894 | 3.000 | 3.000 |

(*continued on next page*)

**Table 4** (*continued*)

| Panel 4-4: Housing Prices for All Cities | | | | | |
|---|---|---|---|---|---|
| Chang and Nonlinear [82] | IV − $t^*$ | — | — | — | — |
| | 3.996 | — | — | — | — |
| | 1.000 | | | | |
| | | 0.996 | 0.998 | | |
| Moon and Perron [26] | $t_a^*$ | $t_b^*$ | $\hat{P}^*_{pool}$ | $t_a^{*B}$ | $t_b^{*B}$ |
| | −11.000 | −6.618 | 0.980 | −10.531 | −6.490 |
| | 0.000 | 0.000 | | 0.000 | 0.000 |
| Pesaran [84] | $P^*$ | CIPS | $CIPS^*$ | | |
| | 5 | −2.035 | −2.035 | | |
| | | 0.095 | 0.095 | | |

statistic, and a stationary sequence determined by the program each time. The results show that all housing prices accept the original assumption that unit root exists, and housing prices are non-stationary.

Considering that the sample spans 151 months, there may be external shocks and structural changes during the period, which will affect the results of the unit root test. This paper intends to continue to test the unit root properties of the panel data on the basis of introducing the Fourier function to approximate the structural changes. Before further analysis, we can observe the time path of the composite housing price index in first-tier, second-tier and third-tier cities in Fig. 1. The figure shows that there is a clear trend change in housing price data around 2016, especially in first-tier cities. Therefore, it is necessary to consider structural changes in unit root tests.

So we report the panel KSS unit root test results for housing prices in first-tier, second-tier, third-tier cities, and the overall city in the right column of Tables 5–8 It contains the sequence of the panel KSS statistic, and the corresponding Bootstrap p-value on the reduced panel, the individual minimum KSS statistic, and the stationary sequence determined for each value with this procedure.

As can be seen from Table 5, housing prices in Beijing, Shanghai, Guangzhou and Shenzhen all have unit roots regardless of the structural changes of time series. However, after adding Fourier function to approximate the structural changes, the *p* value of housing price acceptance unit root original assumption decreases.

Table 6 shows the test results of second-tier cities. Firstly, the panel KSS unit root test is conducted for all 21 cities. And the OU statistic value −2.724 and the corresponding P value 0.000 are obtained, rejecting the original hypothesis that unit root exists in panel data. After SPSM program, it is found that Taiyuan has the smallest individual KSS value −5.038, and the housing price of Taiyuan is a stable series. Then remove the Taiyuan housing price sequence and test the remaining 20 cities again. After removing 14 cities such as Taiyuan and Chengdu, the KSS unit root test of the remaining 10 cities shows that the OU statistic value is −1.257 and the corresponding P value is 0.133, and the original hypothesis that unit root exists in panel data is accepted. The single process continues until the last city. One such process is the panel KSS unit root check based on SPSM. Furthermore, Fourier function is added to the KSS test function to deal with the structure change, and the results are shown in the second column of Tables 5–8 It can be seen that the housing prices of 16 cities, including Taiyuan, were stable time series within the significant level of 10 %. After adding Fourier function to deal with structural changes, two new cities, Chongqing and Ningbo, showed stable characteristics within the significant level of 10 %.

It can be seen from Table 7 that, without considering structural changes, the housing prices of 54 out of 69 third-tier cities, such as Weihai, reject the null hypothesis of unit root at a significant level of 10 %. After accounting for structural changes, only 45 cities reject the original assumption of the existence of unit roots at a significant level of 10 %. The change indicates that structural changes have a significant impact on the stationary of housing prices in some cities.

Table 8 shows the test results of all 94 cities. 61 cities show stable characteristics within the significance level of 10 % in the KSS panel test based on SPSM, and 58 cities show stable characteristics within the significance level of 10 % after adding Fourier function to deal with structural changes. It can be seen that the stable housing price samples tested based on the 94 samples are less than the sum of the stable housing price samples respectively tested by the first, second and third tier cities, indicating that the cross-level housing price is also correlated with each other. Ignoring this cross-sectional correlation tends to result in rejection of the original hypothesis of panel

**Table 5**
SPSM test results in first-tier cities.

| panel KSS unit root with trend | | | | panel KSS unit root with trend and Fourier | | | | |
|---|---|---|---|---|---|---|---|---|
| Seq | OU stat | Min KSS | Series | Seq | OUstat | Min KSS | Fourier(K) | Series |
| 1 | -0.45(0.975) | -1.378 | Guangzhou | 1 | -1.235(0.812) | -1.378 | 3 | Guangzhou |
| 2 | -0.141(0.996) | -0.833 | Shanghai | 2 | -1.131(0.828) | -0.833 | 1 | Shanghai |
| 3 | 0.206(0.956) | 0.090 | Beijing | 3 | -0.723(0.876) | 0.090 | 3 | Beijing |
| 4 | 0.322(0.933) | 0.322 | Shenzhen | 4 | -2.941(0.24) | 0.322 | 1 | Shenzhen |

**Table 6**
SPSM test results in second-tier cities.

| panel KSS unit root with trend | | | | panel KSS unit root with trend and Fourier | | | | |
|---|---|---|---|---|---|---|---|---|
| Seq | OU stat | Min KSS | Series | Seq | OU stat | Min KSS | Fourier(K) | Series |
| 1 | -2.724(0) | -5.038 | Taiyuan | 1 | -3.076(0) | -5.038 | 1 | Taiyuan |
| 2 | -2.608(0) | -4.336 | Tianjin | 2 | -2.915(0) | -4.336 | 3 | Tianjin |
| 3 | -2.517(0) | -4.077 | Changsha | 3 | -2.748(0) | -4.077 | 4 | Changsha |
| 4 | -2.431(0) | -3.855 | Jinan | 4 | -2.68(0) | -3.855 | 1 | Jinan |
| 5 | -2.347(0) | -3.679 | Shenyang | 5 | -2.602(0) | -3.679 | 3 | Shenyang |
| 6 | -2.264(0) | -3.574 | Qingdao | 6 | -2.661(0) | -3.574 | 2 | Qingdao |
| 7 | -2.176(0.001) | -3.188 | Nanchang | 7 | -2.566(0) | -3.188 | 4 | Nanchang |
| 8 | -2.104(0.004) | -3.104 | Hefei | 8 | -2.482(0) | -3.104 | 1 | Hefei |
| 9 | -2.027(0.003) | -3.077 | Fuzhou | 9 | -2.38(0.002) | -3.077 | 2 | Fuzhou |
| 10 | -1.94(0.012) | -2.863 | Wuhan | 10 | -2.378(0) | -2.863 | 1 | Wuhan |
| 11 | -1.856(0.014) | -2.725 | Suzhou | 11 | -2.301(0) | -2.725 | 3 | Suzhou |
| 12 | -1.769(0.025) | -2.628 | Hangzhou | 12 | -2.262(0.002) | -2.628 | 2 | Hangzhou |
| 13 | -1.673(0.042) | -2.534 | Harbin | 13 | -2.224(0.01) | -2.534 | 3 | Harbin |
| 14 | -1.566(0.066) | -2.505 | Chengdu | 14 | -2.12(0.016) | -2.505 | 1 | Chengdu |
| 15 | -1.432(0.133) | -2.478 | Chongqing | 15 | -2.094(0.026) | -2.478 | 2 | Chongqing |
| 16 | -1.257(0.287) | -2.351 | Ningbo | 16 | -1.905(0.07) | -2.351 | 2 | Ningbo |
| 17 | -1.039(0.605) | -1.844 | Xi'an | 17 | -1.622(0.394) | -1.844 | 1 | Xi'an |
| 18 | -0.837(0.823) | -1.648 | Dalian | 18 | -2.235(0.12) | -1.648 | 2 | Dalian |
| 19 | -0.567(0.918) | -1.468 | Nanjing | 19 | -2.39(0.148) | -1.468 | 4 | Nanjing |
| 20 | -0.116(0.807) | -0.662 | Zhengzhou | 20 | -1.982(0.332) | -0.662 | 1 | Zhengzhou |
| 21 | 0.429(0.928) | 0.429 | Xiamen | 21 | -3.358(0.112) | -0.078 | 2 | Xiamen |

unit roots.

Table 9 shows the unit root test results of each tier city after adding Fourier function. The results of first-tier cities show that no city is in a stable state; Results for second-tier cities showed 16 cities were in a stable state. The results of third-tier cities show that 45 cities are stable. There is a differentiated trend in urban housing prices in China, even between cities that are close to each other. This has been found in the research of housing prices in other countries as well [39–42]. The differences in the stability of housing prices reflect both the economic development disparities among regions and the results of local government's regulation of housing prices. Meanwhile, housing prices in different regions also respond differently to the central government's unified regulation. This has been confirmed in studies on credit policies [85].

## 6. Conclusions

This paper examines the stationary of housing prices in 100 cities in China from June 2010 to December 2022. All cities are divided into first-tier cities, second-tier cities, and third-tier cities according to their development levels. Based on the traditional first- and second-generation panel unit root test method, it is found that there are large differences in the stationary of housing prices in first-, second- and third-tier cities. Considering the cross-sectional correlation, structural changes and stationarity differences in housing price data, the panel KSS test is further combined with Fourier function and SPSM for unit root test. It is found that housing prices in first-tier cities are all non-stationary series. And the samples of second- and third-tier cities can be clearly divided into stable housing prices and non-stationary housing prices. After further using the Fourier function to approximate the structural mutation of the data, more second-tier cities showed stable housing prices, while stable housing prices number of third-tier cities has decreased instead.

The policy implications of our study for China are significant. Our findings suggest that in some second- and third-tier cities, housing prices tend to remain stable, and external shocks have only a short-term impact. Therefore, the government can adopt a wait-and-watch approach, allowing the market to correct itself without government intervention. Additionally, the stationarity of housing

**Table 7**
SPSM test results in third-tier cities.

| panel KSS unit root with trend | | | | panel KSS unit root with trend and Fourier | | | | |
|---|---|---|---|---|---|---|---|---|
| Seq | OU stat | Min KSS | series | Seq | OU stat | Min KSS | Fourier(K) | series |
| 1 | −2.603(0) | −5.152 | Weihai | 1 | −2.932(0) | −5.152 | 3 | Weihai |
| 2 | −2.566(0) | −4.221 | Yichang | 2 | −2.926(0) | −4.221 | 4 | Yichang |
| 3 | −2.541(0) | −4.168 | Zhenjiang | 3 | −2.906(0) | −4.168 | 1 | Zhenjiang |
| 4 | −2.517(0) | −4.119 | Xiangtan | 4 | −2.866(0) | −4.119 | 3 | Xiangtan |
| 5 | −2.492(0) | −4.095 | Changshu | 5 | −2.834(0) | −4.095 | 2 | Changshu |
| 6 | −2.467(0) | −4.074 | Lanzhou | 6 | −2.794(0) | −4.074 | 4 | Lanzhou |
| 7 | −2.441(0) | −4.062 | Mianyang | 7 | −2.762(0) | −4.062 | 1 | Mianyang |
| 8 | −2.415(0) | −3.954 | Xining | 8 | −2.762(0) | −3.954 | 2 | Xining |
| 9 | −2.39(0) | −3.822 | Urumqi | 9 | −2.731(0) | −3.822 | 1 | Urumqi |
| 10 | −2.366(0) | −3.694 | Zibo | 10 | −2.711(0) | −3.694 | 3 | Zibo |
| 11 | −2.344(0) | −3.595 | Changchun | 11 | −2.677(0) | −3.595 | 2 | Changchun |
| 12 | −2.322(0) | −3.404 | Guilin | 12 | −2.66(0) | −3.404 | 3 | Guilin |
| 13 | −2.303(0) | −3.350 | Handan | 13 | −2.645(0) | −3.350 | 3 | Handan |
| 14 | −2.285(0) | −3.345 | Huizhou | 14 | −2.627(0) | −3.345 | 4 | Huizhou |
| 15 | −2.265(0) | −3.320 | Baotou | 15 | −2.61(0) | −3.320 | 1 | Baotou |
| 16 | −2.246(0) | −3.302 | Shijiazhuang | 16 | −2.575(0) | −3.302 | 3 | Shijiazhuang |
| 17 | −2.226(0) | −3.170 | Heze | 17 | −2.524(0) | −3.170 | 2 | Heze |
| 18 | −2.208(0) | −3.156 | Foshan | 18 | −2.519(0) | −3.156 | 4 | Foshan |
| 19 | −2.189(0) | −3.148 | Weifang | 19 | −2.499(0) | −3.148 | 1 | Weifang |
| 20 | −2.17(0) | −3.100 | Huai'an | 20 | −2.476(0) | −3.100 | 2 | Huai'an |
| 21 | −2.151(0) | −3.085 | Zhuzhou | 21 | −2.469(0) | −3.085 | 1 | Zhuzhou |
| 22 | −2.131(0) | −3.002 | Wenzhou | 22 | −2.441(0) | −3.002 | 3 | Wenzhou |
| 23 | −2.113(0) | −2.955 | Luoyang | 23 | −2.377(0) | −2.955 | 2 | Luoyang |
| 24 | −2.095(0) | −2.832 | Yantai | 24 | −2.351(0) | −2.832 | 3 | Yantai |
| 25 | −2.078(0) | −2.773 | Zhuhai | 25 | −2.328(0) | −2.814 | 3 | Zhuhai |
| 26 | −2.062(0) | −2.739 | Suqian | 26 | −2.317(0) | −2.739 | 4 | Suqian |
| 27 | −2.047(0) | −2.725 | Huzhou | 27 | −2.282(0) | −2.650 | 1 | Huzhou |
| 28 | −2.03(0) | −2.649 | Dezhou | 28 | −2.231(0) | −2.649 | 3 | Dezhou |
| 29 | −2.015(0) | −2.635 | Zhanjiang | 29 | −2.228(0) | −2.635 | 2 | Zhanjiang |
| 30 | −2(0) | −2.580 | Liaocheng | 30 | −2.218(0) | −2.580 | 3 | Liaocheng |
| 31 | −1.985(0) | −2.567 | Jiaxing | 31 | −2.214(0) | −2.567 | 4 | Jiaxing |
| 32 | −1.97(0) | −2.537 | Zhongshan | 32 | −2.194(0.002) | −2.537 | 1 | Zhongshan |
| 33 | −1.954(0.002) | −2.487 | Ganzhou | 33 | −2.179(0.002) | −2.487 | 2 | Ganzhou |
| 34 | −1.94(0.002) | −2.439 | Jiangmen | 34 | −2.156(0.002) | −2.439 | 1 | Jiangmen |
| 35 | −1.925(0) | −2.436 | Shantou | 35 | −2.114(0.002) | −2.436 | 3 | Shantou |
| 36 | −1.91(0) | −2.429 | Jiangyin | 36 | −2.132(0.002) | −2.429 | 2 | Jiangyin |
| 37 | −1.895(0.004) | −2.416 | Shaoxing | 37 | −2.152(0.002) | −2.416 | 3 | Shaoxing |
| 38 | −1.878(0) | −2.394 | Tangshan | 38 | −2.139(0.006) | −2.394 | 3 | Tangshan |
| 39 | −1.862(0.004) | −2.338 | Beihai | 39 | −2.134(0.012) | −2.338 | 3 | Beihai |
| 40 | −1.846(0) | −2.331 | Nantong | 40 | −2.069(0.018) | −2.331 | 4 | Nantong |
| 41 | −1.829(0.004) | −2.331 | Nanning | 41 | −2.076(0.016) | −2.331 | 2 | Nanning |
| 42 | −1.811(0.006) | −2.325 | Lianyungang | 42 | −2.049(0.03) | −2.325 | 3 | Lianyungang |
| 43 | −1.792(0.004) | −2.280 | Qinghuangdao | 43 | −2.001(0.046) | −2.280 | 1 | Qinghuangdao |
| 44 | −1.773(0.004) | −2.276 | Xuzhou | 44 | −1.987(0.05) | −2.276 | 2 | Xuzhou |
| 45 | −1.753(0.006) | −2.276 | Guiyang | 45 | −1.956(0.078) | −2.276 | 1 | Guiyang |
| 46 | −1.731(0.014) | −2.251 | Dongying | 46 | −1.93(0.104) | −2.251 | 2 | Dongying |
| 47 | −1.709(0.004) | −2.181 | Yangzhou | 47 | −1.948(0.1) | −2.181 | 1 | Yangzhou |
| 48 | −1.687(0.004) | −2.131 | Xinxiang | 48 | −1.932(0.142) | −2.131 | 3 | Xinxiang |
| 49 | −1.666(0.024) | −2.112 | Dongguan | 49 | −1.976(0.116) | −2.112 | 2 | Dongguan |
| 50 | −1.644(0.04) | −2.100 | Kunming | 50 | −1.968(0.152) | −2.100 | 3 | Kunming |
| 51 | −1.62(0.028) | −2.098 | Wuhu | 51 | −1.979(0.124) | −2.098 | 3 | Wuhu |
| 52 | −1.593(0.07) | −2.054 | Zhangjianggang | 52 | −1.974(0.12) | −2.054 | 2 | Zhangjianggang |
| 53 | −1.566(0.076) | −2.053 | Kunshan | 53 | −1.948(0.158) | −2.053 | 3 | Kunshan |
| 54 | −1.536(0.08) | −2.029 | Yancheng | 54 | −1.906(0.158) | −2.029 | 1 | Yancheng |
| 55 | −1.503(0.134) | −2.023 | Liuzhou | 55 | −1.786(0.212) | −1.988 | 2 | Liuzhou |
| 56 | −1.466(0.138) | −1.988 | Changzhou | 56 | −1.931(0.124) | −1.940 | 4 | Yinchuan |
| 57 | −1.425(0.262) | −1.940 | Yinchuan | 57 | −1.945(0.16) | −1.873 | 1 | Langfang |
| 58 | −1.382(0.444) | −1.873 | Langfang | 58 | −1.795(0.2) | −1.838 | 2 | Taizhou |
| 59 | −1.338(0.298) | −1.838 | Taizhou | 59 | −1.757(0.17) | −1.767 | 1 | Wuxi |
| 60 | −1.288(0.24) | −1.767 | Wuxi | 60 | −1.751(0.264) | −1.672 | 3 | Ma'anshan |
| 61 | −1.235(0.308) | −1.672 | Ma'anshan | 61 | −1.669(0.394) | −1.650 | 2 | Hohhot |
| 62 | −1.18(0.338) | −1.650 | Hohhot | 62 | −1.541(0.478) | −1.593 | 3 | Haikou |
| 63 | −1.113(0.594) | −1.593 | Haikou | 63 | −1.452(0.656) | −1.467 | 3 | Quanzhou |
| 64 | −1.033(0.658) | −1.467 | Quanzhou | 64 | −1.444(0.598) | −1.464 | 3 | Taizhou |
| 65 | −0.946(0.538) | −1.464 | Taizhou | 65 | −1.585(0.508) | −1.435 | 4 | Sanya |
| 66 | −0.816(0.7) | −1.435 | Sanya | 66 | −1.457(0.474) | −1.365 | 1 | Jinhua |
| 67 | −0.609(0.634) | −1.365 | Jinhua | 67 | −1.985(0.236) | −1.264 | 3 | Liuzhou |

(*continued on next page*)

**Table 7** (*continued*)

| panel KSS unit root with trend | | | | panel KSS unit root with trend and Fourier | | | | |
|---|---|---|---|---|---|---|---|---|
| Seq | OU stat | Min KSS | series | Seq | OU stat | Min KSS | Fourier(K) | series |
| 68 | −0.232(0.972) | −0.519 | Hengshui | 68 | −2.533(0.11) | −0.616 | 3 | Baoding |
| 69 | 0.056(0.99) | 0.056 | Baoding | 69 | −0.074(0.764) | −0.519 | 2 | Hengshui |

**Table 8**
SPSM test results in all cities.

| panel KSS unit root with trend | | | | panel KSS unit root with trend and Fourier | | | | |
|---|---|---|---|---|---|---|---|---|
| Seq | OU stat | Min KSS | series | Seq | OU stat | Min KSS | Fourier(K) | series |
| 1 | −2.539(0) | −5.152 | Weihai | 1 | −2.892(0) | −5.152 | 3 | Weihai |
| 2 | −2.511(0) | −5.038 | Taiyuan | 2 | −2.887(0) | −5.038 | 1 | Taiyuan |
| 3 | −2.483(0) | −4.336 | Tianjin | 3 | −2.85(0) | −4.336 | 3 | Tianjin |
| 4 | −2.463(0) | −4.221 | Yichang | 4 | −2.815(0) | −4.221 | 4 | Yichang |
| 5 | −2.443(0) | −4.168 | Zhenjiang | 5 | −2.798(0) | −4.168 | 1 | Zhenjiang |
| 6 | −2.424(0) | −4.119 | Xiangtan | 6 | −2.767(0) | −4.119 | 3 | Xiangtan |
| 7 | −2.405(0) | −4.095 | Changshu | 7 | −2.743(0) | −4.095 | 2 | Changshu |
| 8 | −2.385(0) | −4.077 | Changsha | 8 | −2.713(0) | −4.077 | 4 | Changsha |
| 9 | −2.366(0) | −4.074 | Lanzhou | 9 | −2.698(0) | −4.074 | 4 | Lanzhou |
| 10 | −2.345(0) | −4.062 | Mianyang | 10 | −2.673(0) | −4.062 | 1 | Mianyang |
| 11 | −2.325(0) | −3.954 | Xining | 11 | −2.672(0) | −3.954 | 2 | Xining |
| 12 | −2.305(0) | −3.855 | Jinan | 12 | −2.648(0) | −3.855 | 1 | Jinan |
| 13 | −2.287(0) | −3.822 | Urumqi | 13 | −2.631(0) | −3.822 | 1 | Urumqi |
| 14 | −2.268(0) | −3.694 | Zibo | 14 | −2.615(0) | −3.694 | 3 | Zibo |
| 15 | −2.25(0) | −3.679 | Shenyang | 15 | −2.589(0) | −3.679 | 3 | Shenyang |
| 16 | −2.232(0) | −3.595 | Changchun | 16 | −2.6(0) | −3.595 | 2 | Changchun |
| 17 | −2.214(0) | −3.574 | Qingdao | 17 | −2.587(0) | −3.574 | 2 | Qingdao |
| 18 | −2.197(0) | −3.404 | Guilin | 18 | −2.567(0) | −3.404 | 3 | Guilin |
| 19 | −2.181(0) | −3.350 | Handan | 19 | −2.556(0) | −3.350 | 3 | Handan |
| 20 | −2.165(0) | −3.345 | Huizhou | 20 | −2.541(0) | −3.345 | 4 | Huizhou |
| 21 | −2.149(0) | −3.320 | Baotou | 21 | −2.527(0) | −3.320 | 1 | Baotou |
| 22 | −2.133(0) | −3.302 | Shijiazhuang | 22 | −2.5(0) | −3.302 | 3 | Shijiazhuang |
| 23 | −2.117(0) | −3.188 | Nanchang | 23 | −2.461(0) | −3.188 | 4 | Nanchang |
| 24 | −2.102(0) | −3.170 | Heze | 24 | −2.443(0) | −3.170 | 2 | Heze |
| 25 | −2.086(0) | −3.156 | Foshan | 25 | −2.438(0) | −3.156 | 4 | Foshan |
| 26 | −2.071(0) | −3.148 | Weifang | 26 | −2.423(0) | −3.148 | 1 | Weifang |
| 27 | −2.055(0) | −3.104 | Hefei | 27 | −2.404(0) | −3.104 | 1 | Hefei |
| 28 | −2.039(0) | −3.100 | Huai'an | 28 | −2.383(0) | −3.100 | 2 | Huai'an |
| 29 | −2.023(0) | −3.085 | Zhuzhou | 29 | −2.377(0) | −3.085 | 1 | Zhuzhou |
| 30 | −2.007(0) | −3.077 | Fuzhou | 30 | −2.355(0) | −3.077 | 2 | Fuzhou |
| 31 | −1.99(0) | −3.002 | Wengzhou | 31 | −2.354(0) | −3.002 | 3 | Wengzhou |
| 32 | −1.974(0.002) | −2.955 | Luoyang | 32 | −2.305(0) | −2.955 | 2 | Luoyang |
| 33 | −1.958(0) | −2.863 | Wuhan | 33 | −2.284(0) | −2.863 | 1 | Wuhan |
| 34 | −1.944(0) | −2.832 | Yantai | 34 | −2.269(0) | −2.832 | 3 | Yantai |
| 35 | −1.929(0) | −2.773 | Zhuhai | 35 | −2.25(0) | −2.814 | 3 | Huzhou |
| 36 | −1.915(0) | −2.739 | Suqian | 36 | −2.24(0) | −2.739 | 4 | Suqian |
| 37 | −1.9(0) | −2.725 | Suzhou | 37 | −2.214(0) | −2.725 | 3 | Suzhou |
| 38 | −1.886(0) | −2.725 | Huzhou | 38 | −2.205(0) | −2.650 | 1 | Zhuhai |
| 39 | −1.871(0) | −2.649 | Dezhou | 39 | −2.166(0) | −2.649 | 3 | Dezhou |
| 40 | −1.857(0) | −2.635 | Zhanjiang | 40 | −2.162(0) | −2.635 | 2 | Zhanjiang |
| 41 | −1.842(0) | −2.628 | Hangzhou | 41 | −2.153(0.002) | −2.628 | 2 | Hangzhou |
| 42 | −1.827(0) | −2.580 | Liaocheng | 42 | −2.145(0.002) | −2.580 | 3 | Liaocheng |
| 43 | −1.813(0) | −2.567 | Jiaxing | 43 | −2.14(0.002) | −2.567 | 4 | Jiaxing |
| 44 | −1.798(0.002) | −2.537 | Zhongshan | 44 | −2.124(0.008) | −2.537 | 1 | Zhongshan |
| 45 | −1.783(0) | −2.534 | Harbin | 45 | −2.112(0.006) | −2.534 | 3 | Harbin |
| 46 | −1.768(0.006) | −2.505 | Chengdu | 46 | −2.093(0.006) | −2.505 | 1 | Chengdu |
| 47 | −1.753(0.004) | −2.487 | Ganzhou | 47 | −2.088(0.008) | −2.487 | 2 | Ganzhou |
| 48 | −1.737(0.002) | −2.478 | Chongqing | 48 | −2.069(0.008) | −2.478 | 2 | Chongqing |
| 49 | −1.721(0) | −2.439 | Jiangmen | 49 | −2.043(0.012) | −2.439 | 1 | Jiangmen |
| 50 | −1.705(0) | −2.436 | Shantou | 50 | −2.008(0.016) | −2.436 | 3 | Shantou |
| 51 | −1.688(0.006) | −2.429 | Jiangyin | 51 | −2.02(0.016) | −2.429 | 2 | Jiangyin |
| 52 | −1.671(0.014) | −2.416 | Shaoxing | 52 | −2.032(0.014) | −2.416 | 3 | Shaoxing |
| 53 | −1.654(0.012) | −2.394 | Tangshan | 53 | −2.02(0.018) | −2.394 | 3 | Tangshan |
| 54 | −1.635(0.022) | −2.351 | Ningbo | 54 | −2.013(0.022) | −2.351 | 2 | Ningbo |
| 55 | −1.618(0.04) | −2.338 | Beihai | 55 | −1.98(0.042) | −2.338 | 3 | Beihai |
| 56 | −1.599(0.038) | −2.331 | Nantong | 56 | −1.927(0.052) | −2.331 | 4 | Nantong |

(*continued on next page*)

**Table 8** (*continued*)

| panel KSS unit root with trend | | | | panel KSS unit root with trend and Fourier | | | | |
|---|---|---|---|---|---|---|---|---|
| Seq | OU stat | Min KSS | series | Seq | OU stat | Min KSS | Fourier(K) | series |
| 57 | −1.58(0.048) | −2.331 | Nanning | 57 | −1.928(0.066) | −2.331 | 2 | Nanning |
| 58 | −1.56(0.102) | −2.325 | Lianyungang | 58 | −1.904(0.084) | −2.325 | 3 | Lianyungang |
| 59 | −1.538(0.066) | −2.280 | Qinhuangdao | 59 | −1.863(0.11) | −2.280 | 1 | Qinhuangdao |
| 60 | −1.517(0.094) | −2.276 | Xuzhou | 60 | −1.849(0.12) | −2.276 | 2 | Xuzhou |
| 61 | −1.495(0.084) | −2.276 | Guiyang | 61 | −1.822(0.154) | −2.276 | 1 | Guiyang |
| 62 | −1.471(0.066) | −2.251 | Dongying | 62 | −1.799(0.226) | −2.251 | 2 | Dongying |
| 63 | −1.447(0.162) | −2.181 | Yangzhou | 63 | −1.808(0.218) | −2.181 | 1 | Yangzhou |
| 64 | −1.423(0.264) | −2.131 | Xinxiang | 64 | −1.792(0.27) | −2.131 | 3 | Xinxiang |
| 65 | −1.399(0.164) | −2.112 | Dongguan | 65 | −1.818(0.266) | −2.112 | 2 | Dongguan |
| 66 | −1.375(0.312) | −2.100 | Kunming | 66 | −1.807(0.304) | −2.100 | 3 | Kunming |
| 67 | −1.349(0.322) | −2.098 | Wuhu | 67 | −1.809(0.28) | −2.098 | 3 | Wuhu |
| 68 | −1.321(0.358) | −2.054 | Zhangjiagang | 68 | −1.8(0.292) | −2.054 | 2 | Zhangjiagang |
| 69 | −1.293(0.358) | −2.053 | Kunshan | 69 | −1.776(0.322) | −2.053 | 3 | Kunshan |
| 70 | −1.263(0.294) | −2.029 | Yancheng | 70 | −1.742(0.316) | −2.029 | 1 | Yancheng |
| 71 | −1.231(0.462) | −2.023 | Liuzhou | 71 | −1.66(0.43) | −1.988 | 2 | Changhzhou |
| 72 | −1.196(0.584) | −1.988 | Changhzhou | 72 | −1.743(0.314) | −1.940 | 4 | Yinchuan |
| 73 | −1.16(0.668) | −1.940 | Yinchuan | 73 | −1.743(0.34) | −1.873 | 1 | Langfang |
| 74 | −1.123(0.622) | −1.873 | Langfang | 74 | −1.647(0.414) | −1.844 | 1 | Xi'an |
| 75 | −1.085(0.784) | −1.844 | Xi'an | 75 | −1.771(0.278) | −1.838 | 2 | Taizhou |
| 76 | −1.046(0.772) | −1.838 | Taizhou | 76 | −1.748(0.264) | −1.767 | 1 | Wuxi |
| 77 | −1.001(0.822) | −1.767 | Wuxi | 77 | −1.744(0.35) | −1.672 | 3 | Ma'anshan |
| 78 | −0.956(0.828) | −1.672 | Ma'anshan | 78 | −1.7(0.46) | −1.650 | 2 | Hohhot |
| 79 | −0.912(0.91) | −1.650 | Hohhot | 79 | −1.638(0.516) | −1.648 | 2 | Dalian |
| 80 | −0.862(0.946) | −1.648 | Dalian | 80 | −1.629(0.566) | −1.593 | 3 | Haikou |
| 81 | −0.806(0.938) | −1.593 | Haikou | 81 | −1.591(0.698) | −1.468 | 4 | Nanjing |
| 82 | −0.746(0.988) | −1.468 | Nanjing | 82 | −1.467(0.818) | −1.467 | 3 | Quanzhou |
| 83 | −0.686(0.984) | −1.467 | Quanzhou | 83 | −1.464(0.78) | −1.464 | 3 | Taizhou |
| 84 | −0.615(0.966) | −1.464 | Taizhou | 84 | −1.53(0.72) | −1.435 | 4 | Sanya |
| 85 | −0.53(0.98) | −1.435 | Sanya | 85 | −1.473(0.704) | −1.378 | 3 | Guangzhou |
| 86 | −0.429(0.994) | −1.378 | Guangzhou | 86 | −1.465(0.73) | −1.365 | 1 | Jinhua |
| 87 | −0.31(0.97) | −1.365 | Jinhua | 87 | −1.664(0.582) | −1.264 | 3 | Liuzhou |
| 88 | −0.16(1) | −0.833 | Shanghai | 88 | −1.775(0.522) | −0.833 | 1 | Shanghai |
| 89 | −0.047(0.994) | −0.662 | Zhengzhou | 89 | −1.746(0.516) | −0.662 | 1 | Zhengzhou |
| 90 | 0.076(1) | −0.519 | Hengshui | 90 | −1.974(0.446) | −0.616 | 3 | Hengshui |
| 91 | 0.224(0.998) | 0.056 | Baoding | 91 | −1.22(0.802) | −0.519 | 2 | Baoding |
| 92 | 0.28(0.978) | 0.090 | Beijing | 92 | −1.601(0.706) | −0.078 | 2 | Beijing |
| 93 | 0.376(0.974) | 0.322 | Shenzhen | 93 | −0.723(0.876) | 0.090 | 3 | Shenzhen |
| 94 | 0.429(0.978) | 0.429 | Xiamen | 94 | −2.941(0.24) | 0.322 | 1 | Xiamen |

prices in most provinces of China indicates a positive outlook for real estate development in these areas. The rising trend of housing prices comes from the impact of economic fundamental factors such as per capita and gross domestic product.

However, our study also highlights the need for targeted regulatory interventions for some cities. Four first-tier cities and some second- and third-tier cities show unstable housing prices and may require active intervention to prevent the occurrence of housing price bubbles. Regulatory measures such as purchase restrictions, transaction taxes, property taxes, and credit policies can be effective

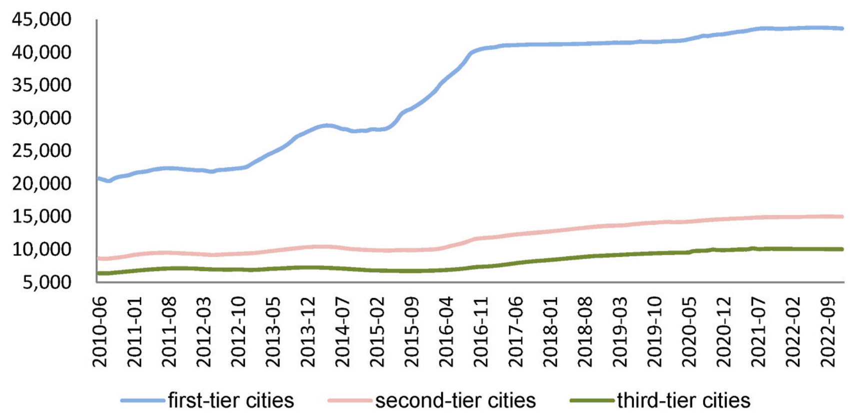


**Fig. 1.** Hundred cities housing price index.

**Table 9**
The unit root test results of housing prices in various cities.

| | panel KSS unit root with trend | | panel KSS unit root with trend and Fourier | |
|---|---|---|---|---|
| | stable | non-stable | stable | non-stable |
| First-tire cities | | Beijing, Shanghai, Guangzhou, Shenzhen | | Beijing, Shanghai, Guangzhou, Shenzhen |
| Second-tier cities | Taiyuan, Tianjin, Changsha, Jinan, Shenyang, Qingdao, Nanchang, Hefei, Fuzhou, Wuhan, Suzhou, Hangzhou, Harbin, Chengdu | Chongqing, Ningbo, Xi’an, Dalian, Nanjing, Zhengzhou, Xiamen | Taiyuan, Tianjin, Changsha, Jinan, Shenyang, Qingdao, Nanchang, Hefei, Fuzhou, Wuhan, Suzhou, Hangzhou, Harbin, Chengdu, Chongqing, Ningbo | Xi’an, Dalian, Nanjing, Zhengzhou, Xiamen |
| Third-tier cities | Weihai, Yichang, Zhenjiang, Xiangtan, Changshu, Lanzhou, Mianyang, Xining, Urumqi, Changchun, Guilin, Handan, Foshan Huizhou, Baotou, Heze, Shijiazhuang, Yantai, Weifang, Huai’an, Zhuzhou, Wenzhou, Luoyang, Yancheng Zhuhai, Suqian, Xuzhou, Zibo, Dezhou, Wuhu, Zhanjiang, Liaocheng, Jiaxing, Zhongshan, Ganzhou, Jiangmen, Shantou, Jiangyin, Shaoxing, Tangshan, Nantong, Nanning, Lianyungang, Beihai, Qinghuangdao, Huzhou, Guiyang, Dongying, Yangzhou, Xinxiang, Dongguan, Kunming, Zhangjiagang, Kunshan, | Liuzhou, Changzhou, Yinchuan, Langfang, Taizhou, Wuxi, Ma’anshan, Hohhot, Haikou, Quanzhou, Taizhou, Sanya, Jinhua, Hengshui, Baoding | Weihai, Yichang, Zhenjiang, Xiangtan, Changshu, Lanzhou, Mianyang, Xining, Urumqi, Zibo, Changchun, Guilin, Handan, Huizhou, Baotou, Shijiazhuang, Heze, Foshan, Weifang, Huai’an, Zhuzhou, Wenzhou, Luoyang, Yantai, Huzhou, Suqian, Zhuhai, Dezhou, Zhanjiang, Liaocheng, Jiaxing, Zhongshan, Ganzhou, Jiangmen, Shantou, Jiangyin, Shaoxing, Tangshan, Beihai, Nantong, Nanning, Lianyungang, Qinghuangdao, Xuzhou, Guiyang | Dongguan, Yangzhou, Xinxiang, Dongguan, Kunming, Wuhu, Wuxi, Zhangjiagang, Kunshan, yancheng, Changzhou, Yinchuan, Langfang, Taizhou, Ma’anshan, Hohhot, Haikou, Quanzhou, Taizhou, Sanya, Jinhua, Liuzhou, Baoding, Hengshui, |
| All Cities | Weihai, Taiyuan, Tianjin, Yichang, Zhenjiang, Xiangtan, Changshu, Changsha, Lanzhou, Mianyang, Xining, Jinan, Urumqi, Zibo, Shenyang, Changchun, Qingdao, Guilin, Handan, Huizhou, Baotou, Shijiazhuang, Nanchang, Heze, Foshan, Weifang, Hefei, Huai’an, Zhuzhou, Fuzhou, Wenzhou, Luoyang, Wuhan, Yantai, Zhuhai, Suqian, Suzhou, Huzhou, Dezhou, Zhanjiang, Hangzhou, Liaocheng, Jiaxing, Zhongshan, Harbin, Chengdu, Ganzhou, Chongqing, Jiangmen, Shantou, Jiangyin, Shaoxing, Tangshan, Ningbo, Beihai, Nantong, Nanjing, Qinghuangdao, Xuzhou, Guiyang, Dongying | Lianyungang, Yangzhou, Xinxiang, Dongguan, Kunming, Zhangjiagang, Kunshan, Yancheng, Liuzhou, Changzhou, Yincuan, Langfang, Xi’an, Hohhot, Wuhu, Xiamen, Ma’anshan, Wuxi, Dalian, Haikou, Nanjing, Quanzhou, Taizhou, Jinhua, Sanya, Guangzhou, Shanghai, Zhengzhou, Hengshui, Baoding, Beijing, Shenzhen, Taizhou | Weihai, Taiyuan, Tianjin, Yichang, Zhenjiang, Xiangtan, Changshu, Changsha, Lanzhou, Mianyang, Xining, Jinan, Urumqi, Zibo, Shenyang, Changchun, Qingdao, Guilin, Handan, Huizhou, Baotou, Shijiazhuang, Nanchang, Heze, Foshan, Weifang, Hefei, Huai’an, Zhuzhou, Fuzhou, Wenzhou, Luoyang, Wuhan, Yantai, Huzhou, Suqian, Suzhou, Zhuhai, Dezhou, Zhanjiang, Hangzhou, Liaocheng, Jiaxing, Zhongshan, Harbin, Chengdu, Ganzhou, Chongqing, Jiangmen, Shantou, Jiangyin, Shaoxing, Tangshan, Ningbo, Beihai, Nantong, Nanjing, Lianyungang | Qinghuangdao, Xuzhou, Wuhu, Guiyang, Dongying, Yangzhou, Xinxiang, Dongguan, Kunming, Zhangjiagang, Kunshan, Yancheng, Changzhou, Yincuan, Langfang, Xi’an, Taizhou, Wuxi, Ma’anshan, Hohhot, Dalian, Haikou, Nanjing, Quanzhou, Taizhou, Sanya, Guangzhou, Jinhua, Liuzhou, Shanghai, Zhengzhou, Hengshui, Baoding, Beijing, Shenzhen, Xiamen |

in this regard. Adopting different regulatory policies for different cities, based on their unique characteristics, will improve the effectiveness of real estate management in China.

Overall, our study provides crucial insights for policymakers in China to formulate more effective and targeted real estate regulations to ensure long-term stability in the housing market.

To enhance the robustness of our findings, our study only focused on analyzing the differences in stationarity among cities of different tiers in terms of housing prices. However, there are multiple factors that may affect the stationarity of housing prices, such as GDP, bank credit, population, and land supply. Therefore, further research analyzing the factors responsible for the heterogeneity of stationarity, can help in formulating more effective policies. Another limitation of our study is related to the Fourier functions utilized to handle potential structural changes in time series. While this method proved successful in our study, we did not delve into the information and economic significance of such changes. Therefore, a prompt suggestion is that future studies may focus on analyzing the implications of structural changes, as well as on the utilization of alternative methods to capture potential change in time series.

## Data availability statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## CRediT authorship contribution statement

**Na Bian:** Writing – original draft, Resources, Data curation, Conceptualization. **Yiguo Chen:** Writing – review & editing, Software, Methodology, Formal analysis.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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