Capture the abrupt changes in Asian residential property markets

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a b s t r a c t

In this paper, studies on the real estate markets mainly focused on the relationship between abrupt change points and corresponding political issues and economic collapse. Within the past statistical framework, change-point detection technique was widely considered based on large and long data sets. Few studies considered the situation where a limited size of time-series data sets is available in the real estate markets. To fill in this gap, the wavelet analysis with minimax threshold is introduced in this paper. By comparing Daubechies LA(8), wavelet analysis with minimax threshold is a versatile and powerful approach to the analysis of residential data as they are flexible in their function form and provide a robust computational method even with a small sample size. The detected change points reflect some significant political issues and economic collapses. It can be shown from the empirical result that a "diffusion relationship" happened from one location to another.

Keywords:
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Jump point
Property market
Economic events
Emerging market
CUSUM test

1. Introduction

Real estate has been long regarded as one of the safest investment products in financial markets. As such, investors are able to build a secure foundation for their wealth (Haight & Singer, 2005). Over the past ten years, as the outbreak of cataclysmic events (such as human swine flu, Severe Acute Respiratory Syndrome [SARS], credit risk arisen from the bankruptcy of Lehmann Brothers, and Asian financial crisis) occurred more frequently, security markets have been fluctuating. Meanwhile, real estate markets have been relative stable, and thus become more popular among investors. Due to its durable nature (Malpezzi & Wachter, 2005), it is believed that real estate serves as a hedging tool against inflation when its return exceeds, or at least equals to, the rate of inflation (Worzala & Sirmans, 2003). Therefore, the benefits received over time create a compounding effect on real estate returns, which, unlike those of some other instruments in the equity market, are more than simply compensations by means of a predictable income stream (Haight & Singer, 2005). Recently, many researchers have attempted to find a strategic investment in the real estate market (Falkenbach, 2009; Hui & Yu, 2012; Hui, Lau, & Lo, 2009, 2014; Nguyen, van der Krabben, & Samsura, 2014), with their major concern being the risk-change point relationship (Ling & Hui, 2013).

Though real estate is a comparatively safe investment option, its return is still inevitably affected by external factors. Various demand shocks, such as political events, economic crises, and epidemic diseases, may give rise to changes. To some extent, nearly all those changes are regarded as sudden drops (or rebound), which cause a series of short- and long-term effects. Pessimistically, some investors consider that a change may ultimately lead to capital losses. Such awareness is the reason why investors are unwilling to pay a premium for the security of the rights when facing uncertainty (Tu & Bao, 2009). Hence, identifying those sudden changes could reveal important findings that provide crucial information for policy-making and investment decisions, as these changes contain some hidden information that might not be easily observable. A change of that nature is usually termed as a jump point, which refers to a long-term widespread change of the fundamental structure, rather than a micro scale or short-term output (Hansen, 2001).

This paper intends to detect the change points and the corresponding events' level of influence on residential price indices (calculated from transaction prices) of four different cities (i.e. Singapore, Hong Kong, Shanghai, and Taipei). In the past few decades, numerous researchers have introduced a variety of methodologies to detect jump point(s). However, these approaches mostly require large datasets (Andrew & Meen, 2003; Vuorenmaa, 2005). Since the pricing data for real estate market of most developing countries is not large enough to meet the requirement of these methods, it renders comparisons of the impact of international events between developing countries, or between developed and developing countries, difficult.

By contrast, the wavelet analysis, which only requires smaller datasets, could address this issue. Specially, the techniques introduced by Ip, Wong, Xie, and Luan (2004) and Donoho and Johnstone (1994) for the wavelet analysis and change point detection, would be applied to study residential property prices of the four renowned Asian cities. More importantly, in order to examine the location effect among these cities, a comparison between the spreading out effect relationship is to be conducted as well.

This paper is structured as follows. Section 2 presents the literature review as to change point and the methods previously used in its detection. Section 3 introduces the wavelet analysis for jump point detection. Section 4 presents the results of the empirical studies and discusses the rationale that lies behind the detected change points. Finally, Section 5 draws a conclusion.

2. Literature review

2.1. A brief review on change points

The detection of change points is an important topic in macroeconomic studies, and it requires the development of mathematical tools. The most usual methods are Fourier transforms and related statistical methods. When studying the price changes in French real estate market, Rachev and SenGupta (1993) found and discussed the "stability" properties of Laplace model and a mixture model of Laplace and Weibull. Lombard (1988) utilized the Fourier analysis to detect the cusps. In the empirical studies, Fourier transform can only convert the time-series data into a signal process, without retaining the other information, e.g. the location and the frequency of the change points. It indicates that it is really hard to see the location impact within the time horizon domain. To overcome the weakness arising from Fourier analysis, Muller (1992) developed a nonparametric regression method to examine the location and the scale of a cusp in a time-series, which is based on the boundary kernels framework. Nevertheless, no sophisticated standard for the jump point detection is fully accepted. To improved Muller's model (1992), Eubank and Speckman (1995) introduced another semiparametric method and a least-square estimator to detect the discontinuities in one of the derivatives of regression functions. The major contribution in this approach is that smooth higher derivatives for the function are no longer a requirement. However, both of the above two approaches demand a large data set. Andrew and Meen (2003) investigated the aggregate time-series transaction data in Britain real estate by employing the dummy variables in the regression model. A significant relationship was found between the house prices and transactions, with a detected change point during the 1990s (decreasing transactions). Lavielle and Teyssiere (2006) discovered some major changes which matched with important social and economic events when they studied the bivariate series of returns on FTSE 100 and S&P 500 index. They also analyzed multivariate series of returns on real and artificial financial markets and achieved similar results. Another study by Strikholm (2006) found a sequential method and applied it on the US ex-post real interest rate series. In piecewise linear structural break models, this method can estimate the number of breaks. Hillebrand and Schnabl (2006) segmented the Yen/Dollar exchange rate with a change point detector, to examine whether Japanese foreign exchange interventions had an obvious impact on the volatility of the exchange rate. Furthermore, Bourassa, Haurin, Haurin, Hoesli, and Sun (2009) discussed the influence of the housing characteristics on the market appreciation rate, by constructing a repeated sale model of residential single-family properties. They concluded that the market-wide bubbles, the changes of local and national macroeconomic variables contributed to the average change in real estate prices. But their method only works on hypothesizing the house will appreciate at different rates depending on the characteristics of the property and change in the strength of the housing market.

Since wavelet analysis contains some expected properties, it is a good tool to handle the transaction information from the real estate market, without any hypothesis on the objective market (e.g. market equilibrium). Donoho and Johnstone (1994) generalized the traditional wavelet detection methods. They only considered small samples and developed selective wavelet reconstruction technique. Wang (1995) employed a technique to pick up the jumps and sharp cusps by detecting the significantly large absolute values over a determined threshold from the wavelet-transformed data. The assumption of uncorrelated white noise for the time series is the major limitation of this technique. Johansen et al. (2000) suggested a cointegration model with piecewise linear trend and a predetermined number of known break points. Inoue (1999) also applied the cointegrating rank and developed the test for trend breaks. However, the method of Johansen et al. (2000) and Inoue (1999) only rely on the parametric models. Ip et al. (2004) suggested a wavelet detection analysis for jumps or cusps, which can be applied on discontinuous functions with noise. By proposing this approach on the daily exchange rate of USD/DEM between 1 August 1989 and 31 July 1991, they found evidence to support that all the points detected can be explained by important economic and political events. They also compared their method with three traditional approaches (Wang, 1995; Xie, 1993; Yin, 1988), and emphasized that their new method is more flexible with less benchmark selection bias. Later, Lai and Huang (2007) introduced wavelet transform technique on the Chinese real estate stock market. However, they limited themselves to the qualitative analysis while being lack of the data supporting.

Previous studies proved that wavelet analysis is a versatile and powerful technique for the change point detection. Two of the above methods, Ip et al. (2004) and Donoho and Johnstone (1994) would be employed in the following change point analysis. The method suggested by Ip et al. (2004) has also been applied in two related researches (Hui, Liang, Ip & Ho, 2013; Hui, Liang, Zhong & Ip, 2015).

2.2. Major events from 1999 to 2009

It is supposed that several global and Asian events would show significant impacts on the targeted real estate market.

2.2.1. Global events

① A series of organized terrorist attacks occurred on September 11, 2001 in the United States. At that morning, four commercial passenger flights were hijacked by 19 Al-Qaeda terrorists. The hijackers then crashed down the Twin Towers of the World Trade Center, one of the famous landmarks in New York City, causing more than 3000 deaths. A great economic shock was reflected in the US and global markets. The New York Stock Exchange (NYSE), the American Stock Exchange (AMEX), and NASDAQ were forced to be closed until September 17. The Dow Jones Industrial Average (DJIA) stock market index dropped by 684 points, or 7.1%, to 8,921, which is one of the most daily declines, on the reopen day. It is believed that 9/11 would cause some side effects on global real estate markets. From the perspective of world affairs, the tragedy indicated that terrorism had already become a global problem. From the perspective of the financial market, events such as these can be regarded as a new source of risk, which is required to be recognized and decisions adjusted accordingly. People are also concerned as to whether the real estate market would also undergo a similar adjustment process after 9/11.

② The subprime mortgage crisis since 2007 caused a dramatic rise in mortgage defaults and foreclosures in the United States, and led to major declining influences on banks and financial markets globally. The risk of this crisis existed from 1990s, and it finally broke in 2007, exposing the widespread shortages not only in mortgage regulations, but also in the global financial system. In recent years, about 80% of US subprime mortgages were adjustable-rate mortgages. As the US real estate prices reached the pink and then decreased in 2006, refinancing became a great trouble. In this case, the adjustable-rate mortgages would reset at higher interest rates, and then the mortgage defaults enormously increased. Securities and derivatives backed by subprime mortgages, which had been widely purchased by financial companies, lost most of their value in a short time. It brought a mass reduce of the asset held by many banks and even US government-sponsored enterprises, which soon threatened the credit grades of the countries and corporates around the world. It is believed that this serious crisis from US would increase the investor's worry on the Asian real estate markets, which had experienced a continuous expansion in 2000s. The subprime mortgage crisis suggests a possibility that low quality mortgages exist in these markets. If the amount of these mortgages continues to increase due to the rapid expansion of real estate markets, default risk would increase. By the time when mortgage defaults indeed occur, the real estate market would face a downward pressure. On

the other hand, the financing capability of developers would be also reappraised if they hold back too much land. The developers may decrease the price when they do not possess enough liquid assets. As a result, investors would be more aware of the default risk and the downside risk of housing prices when investing in Asian real estate markets, which may slow down the development of these markets.

③ The bankruptcy of Lehman Brothers in mid-September 2008 further triggered the credit crisis for the financial corporates and many of them dismissed lots of employees to cut down the operation cost. From the investors' viewpoint, the real estate market was hit the worst by the global financial crisis.

2.2.2. Asian cities' events

2.2.2.1. Singapore

④ In 2001, the unemployment rate of Singapore reached the highest level in 15 years and the worst recession since 1970s had been recorded. About 10 million square feet of offices were not in use. Residential market, office market and rental market all dropped drastically. High unemployment rate and severe recession forced many households to postpone their homeownership plans as their instable income. As a result, housing demand in this period was supposed to fall. The high vacancy rate in office market may indicate the further economic depression existed, which showed indirect pressure on housing market as well.

⑤ When it came to Feb 2006, a 5e10% rise in luxury residential market was announced, due to the oversea strong demand. Straits Times Index also rose up to its 6-year top. It is expected that the price increase for the luxury residential properties would have spillover effects to the other parts of residential market. As the prices of luxury houses had risen, the potential return of non-luxury houses would become relatively higher and more attractive for the local investors.

⑥ Since July 1st, 2006, the Central Provident Fund (CPF) members in Singapore were restricted on their use of CPF saving for multiple property purchases. Previously, there was no such restriction on the use of CPF in the purchase of the second apartment. However, under the new policy, an individual can do so only when half of the prevailing Minimum Sum in his/her Ordinary and Special Accounts were set aside when he/she buys a second apartment after 1 July 2006. The Singaporean Government tended to ensure that CPF members would have enough retirement protection, without spending too much money on property investment. This policy change was supposed to have negative influence on the property market since the cost incurred in home purchases becomes higher for potential buyers than it was before the introduction of this restrictive policy initiative.

2.2.2.2. Taipei

⑦ In Apr 2004, Taiwan's economic recovery was expected to decelerate because a dispute over the island's presidential election triggered mass protests, which threatened spending and investment. The impasse hurt Taiwan's property market, due to the 50% fall of apartment sales in the following week after the election, and the TWSE Construction index also declined by 10% after the election. Before the election, the construction and property sectors were the best-performing industries that year, recording a rise by 65 percent compared with a year before. Even though the decline of the stock market may be temporary, it may still possibly influence the construction and property sectors, and subsequently the real estate markets (in the supply side) in the long-run.

2.2.2.3. Shanghai and Hong Kong

⑧ The Severe Acute Respiratory Syndrome (SARS) started to break out in Guangdong Province of China in November 2002. The epidemic soon spread across the country, including Hong Kong, within a few weeks' time. Consequently, this new disease nearly lasted for one year, and resulted in 349 deaths and approximately 4 billion US dollars loss. To some extent, this unpredictable worldwide disaster generated some obviously negative impacts on the real estate market, and significant drops in residential markets can be observed in Shanghai and Hong Kong during this year. Since real properties were less liquid, overseas investors would show lower interest in these markets during that period. Even many local citizens would delay their home purchase decisions. Before the spread of the disease was under control, housing prices were to be falling.

⑨ The Ministry of Land and Resources (MLR) of China stipulated Notification No. 71 in March 2004. This notification required that after 31 August 2004, tenders or auctions became the only ways to sell the state-owned urban land for real estate development. The newly built land transaction system introduced a market mechanism into the land sale procedures in Chinese urban areas, and supposes to set up an open and fair land allocation environment. The auction price of land would be formally included in the eventual housing prices. It is uncertain as to whether the housing prices would rise or fall directly due to this new policy. However, it is expected that the development of real estate market would accelerate (see Fig. 1)

3. Data source

This section examines the time-series relationship between the residential real estate price index of the selected four Asian cities (i.e. Singapore, Hong Kong, Shanghai, and Taipei), from 1999Q1 to 2009Q2. The reason behind the use of quarterly indices is that the changes in real estate markets are much slower, compared to those in stock markets (Tse, 2001). And the wavelet transforms of quarterly indices are better choices to discuss whether the change points can be explained by political events or economic crises, since the change in real estate market may not appear immediately after the shocks. Regarding the data sources, property price data of Singapore is gathered from Singapore Department of Statistics; housing price data of Hong Kong is gathered from Rating & Valuation Department; the real estate price index of Shanghai is collected from the China Data Online, and that of Taipei from the Taiwan Real Estate Research Center of the Taiwan Political University. A summary of descriptive statistics for these markets are shown in Table 1.

Fig. 2 shows the time series plot of the residential real estate indices of the four Asian cities. The trends of Singapore and Taipei

Table 1
Summary of descriptive statistics.

	Shanghai	Hong Kong	Singapore	Taipei
Mean	106.3381	90.0595	129.4157	84.1218
Median	104.9	91.85	122.3	78.4035
Standard Variance	9.0078	17.9174	19.5951	15.3692
Minimum	95.8	58.4	106.88	68.4162
Maximum	129.1	125.3	177.5	117.11
Range	33.3	66.6	70.62	48.6937
Kurtosis	0.4047	0.4157	0.7214	0.2874
Skewness	1.0969	0.2584	1.29194	1.0918

indices are noticeably similar. At first, they both are slightly increasing, then gradually decreasing yet relatively stable for a long period of time till 2005Q3. After that, they dramatically rocketed to their peaks in 2008Q2e2008Q3. In contrast, the indices of Shanghai and of Hong Kong seem to be symmetric over time. Before 2004, Shanghai's index had kept an incredible upward trend, while the Hong Kong index gradually reached its 10-year lowest point. By 2004, however, the two cities' market performance made a V turn.

In order to examine the linear relationship between the residential housing markets among those four cities, we calculate the correlation coefficients, as shown in Table 2A. It is apparent that the correlation coefficients of any combination of Hong Kong, Singapore, and Taipei markets are quite similar, meaning that any combination of these three cities is nearly perfectly correlated (the correlated coefficients is 1). On the contrary, Shanghai and the other three markets are negative correlated and the coefficients are
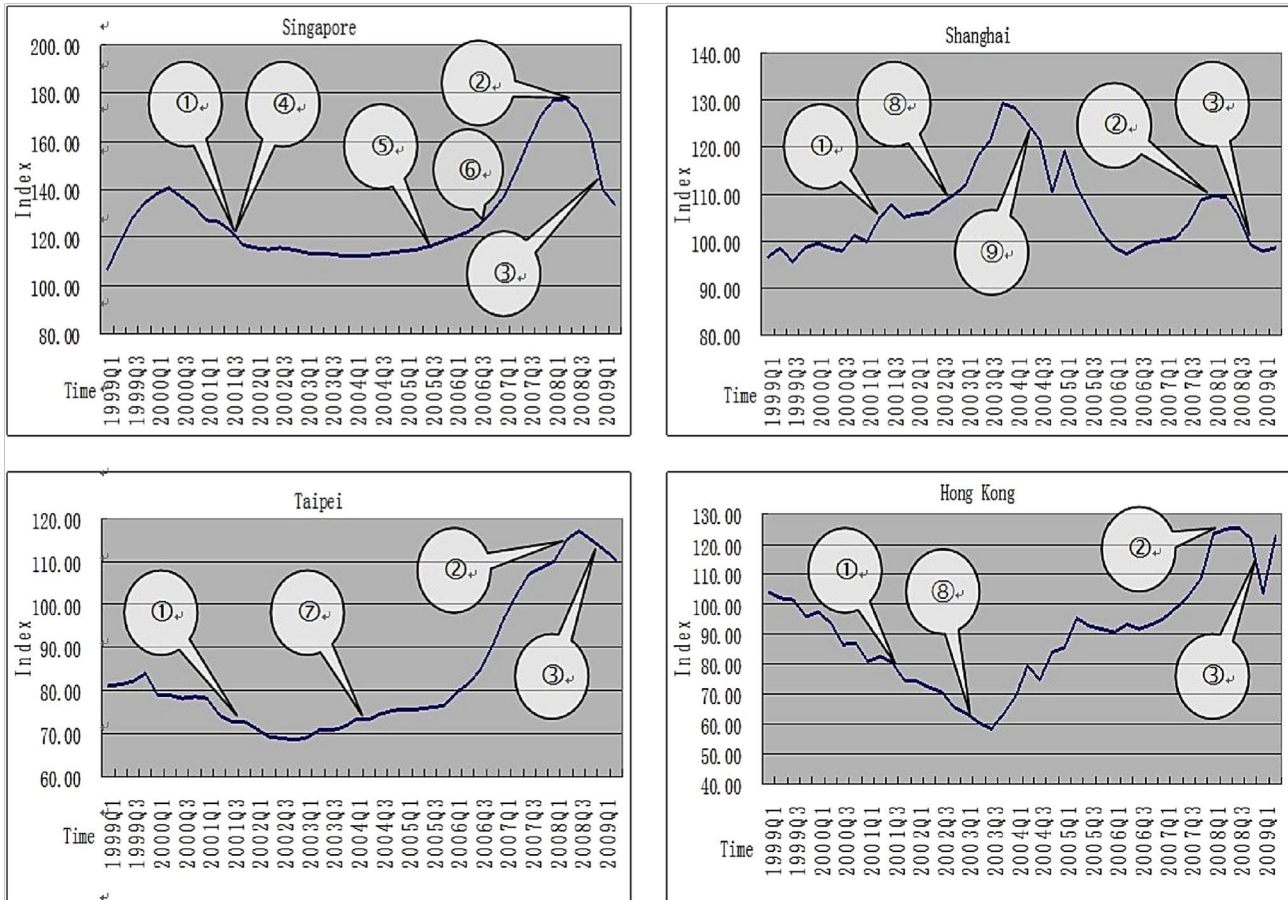

Fig. 1. Time series plot for the residential real estate index of the four Asian cities corresponding to the major events ①~⑨
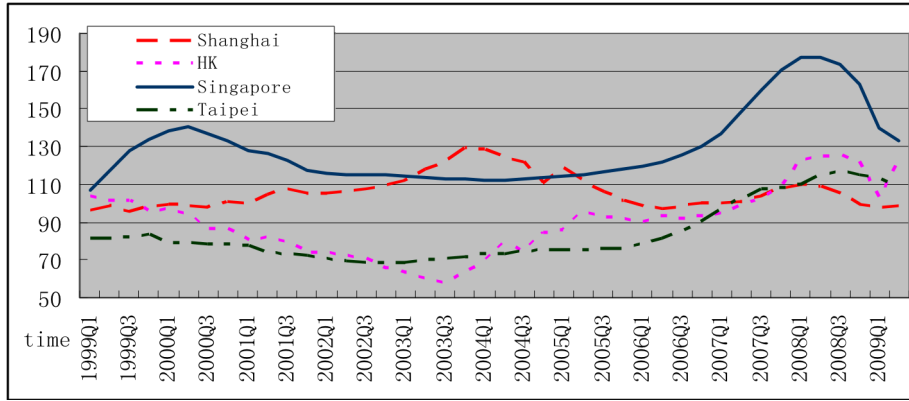
Fig. 2. Time series plot of the Asia residential real estate market.

Table 2A
Correlation coefficients.

	Shanghai	Hong Kong	Singapore	Taipei
Shanghai	1	0.53058	0.29443 0.81269	0.34088
Hong Kong		1		0.87626
Singapore			1	0.88737
Taipei				1

smaller. For example, the correlation between Shanghai and Singapore is 0.29443. However, this small number shows neither a weak linear relationship nor no linear relationship between them. In addition, as Meen (2002) indicated, the real estate index may indicate the feature of weakly information efficient. The reason of testing whether the selected real estate markets cater for the efficient markets hypothesis (EMH) is largely due to the issue regarding the stationarity of the data (Canarella, Miller, & Pollard, 2012). They also conclude that in an efficient market, the rate of capital gain should display unpredictable (i.e. without unit roots) behaviors. As a result, it is reasonable to conduct separate unit-root tests for the four property markets. The results (Table 2B) show that all the real estate markets are stationary after 1st differencing, which means that in the efficient markets, the price index fully contains all the market information. In other words, the information such as the global events is embedded in the collected data set.

4. Detection of change point by wavelet analysis

By the discussion shown above, define $x(t) = y(t) - y(t-1)$, $t \in R$:

which coincides with the EMH setting and stationary. As the collected data are from the real estate markets in nature, consider the following nonparametric model that introduced by Ip et al.

Table 2B
ADF Unit-Root test of the residential real estate index.

	(Original data)		(1st difference of the data)	
	Coefficient	P-value	Coefficient	P-value
Singapore	2.8364	0.0623 0.7589	3.8067	0.0062
Taipei	0.9504	0.1931	2.1679	0.0012
Shanghai	2.2491	0.8768	5.5162	0.0000
Hong Kong	0.5198		17.440	0.0001

Note: The hypothesis of the above unit-root test is H_0: the index has a unit root against H_1: the index does not have a unit root.

(2004) and improved by Hui, Yu, and Ip (2010) and Hui, Liang, Ip & Ho (2013):

$$x(t) = s(t) + n(t), \quad t \in R; \qquad (1)$$

where $x(t)$ is the data we collected, which is often disturbance by the noise term, s(t) is the true value of the data, a deterministic function which only has finite discontinuous points. n(t) is a zero mean stationary noise. Consider the following case: the true value s(t) is assumed to possess p change points, i.e., there exists $t_1 < t_2 < \cdots < t_p$, such that

$$s(t_u - 0) \neq s(t_u + 0), \qquad u = 1, 2, \ldots, p; \qquad (2)$$

the value at t_u is termed as jump point, where $s(t_u\ 0)$ and $s(t_u\ þ\ 0)$ are the left-limiting and right-limiting values of s(t) respectively and p is a positive integer. Except these points, s(t) is differentiable on R with bounded derivatives. By the definition shown above, (2) is designed for detecting the long-term changes.

Thus far, the problem of detecting the change points is turned to test following hypothesis:

$$H_0 : x_1\ ¼\ x_2\ ¼\ /\ ¼\ x_{pþq}$$

$$H_1 : x_1\ ¼\ x_2\ ¼\ /\ ¼\ x_j s x_{jþ1}\ ¼\ /\ ¼\ x_{pþq}$$

With unknown index j, each x_j is defined as the expected value of the data at time j. However, as (1) indicated, the model is nonparametric oriented, which means the model does not depend on any specific distribution. Then it is impossible to test the mean value of the time series directly. Instead, the discrete wavelet transform is considered. Define the wavelet function by

$$j_{j;k}ðtÞ\ ¼\ 2^{\frac{j}{2}} 2^j t\ \ k \qquad (3)$$

where jðtÞ is named the mother wavelet. Then the wavelet transform of a function s(t) is

$$w_{j;k}\ ¼\ Z\ sðtÞj_{j;k}ðtÞdt;\ k2Z;\ j\ ¼\ 1;2;/: \qquad (4)$$

which will generate in a sequence of wavelet coefficients. . Consider the mother wavelet jðtÞ via Meyer function defined by

$$\qquad (5)$$

Moreover, the scale function is defined as

$$4ðtÞ \quad ¼ð2pÞ \quad \cos\ p2n\ 23pjwj\ \ 1 \quad ; \quad 23p\ jwj43p \qquad (6)$$

where vðaÞ ¼ $a^4 35\ \ 84a\ þ\ 70a^2\ \ 20a^3$; $a2½0;1$

In change point detection, the unknown function s(t) may contain one or more discontinue jump points, therefore, an adaptive method by Donoho and Johnstone (1994) is needed. Let

$$h_H ðw_i;\ lÞ\ ¼\ w_i Ifjw_ij>lg \qquad (7)$$

$$q_i\ ¼\ h_s ðw_i;lÞ\ ¼\ sgn ðw_iÞ ðjw_ij\ \ lÞþ \qquad (8)$$

be hard threshold and soft threshold values respectively, where w_i, l are the wavelet coefficient as well as threshold benchmark value and $Ifjw_ij>lg$ is the indicator function such that

If $|w_{i,j}| > g \approx 10;$, j others $w^j > l$. To simplify the presentation, only the soft threshold below would be discussed. Define the minimax quantities:

$$L_n^* \equiv \inf_{l} \sup_{m \, n \, \vDash \, \min^m \, \vDash \, 1} \frac{\min(l \, ; m)}{\frac{1}{m^2}} \qquad (9)$$

$$l_n^* \equiv \text{the largest } l \text{ attaining } L_n^* \text{ above} \qquad (10)$$

where m is the mean value of the true value function $s(t)$. As $x(t)$ at each time t should have the same mean of true function $s(t)$, the Equation (9) indicates that we start to consider the threshold by setting $m(1) \approx l$, it is quite straightforward to acquire L_1^*, at time 2, select the largest m from $m(1)$ and $m(2)$, and substitute m and $l \approx L_1$ in (9), we got L_2, by following the same procedure above till the last record, we have a series of $\{L_k^*\}$, $k \approx 1, 2, 3 \dots n$. The largest one in the series $\{L_k\}$ is temporary treated as threshold benchmark. However, for the extreme case when the collect data may reach zero or infinity, it is reasonable to consider the analogue quantities where the supremum over the interval $[0,\infty]$ is replaced by the supremum over the endpoints $f0;\infty g$:

$$_n^0 \equiv \inf_{\lambda} \sup_{\mu \in 0} \frac{L(11) \min(l \, ; m)}{f;\infty g \, n1^0 \vDash \min^{m^2} \vDash 1} \qquad$$

$_2$ It is clear that $_{fi} L_n \approx L_n$. Then it is expected to estimate the L -loss to find out the minimax threshold l_n, with the following equality holds

$_2$

$$E \qquad\qquad cq* \; ^q$$

$$_{2;n} \approx_1 X_{2\dots} \min_n l_n^*; \; ^q \varepsilon_i = \varepsilon^{\varepsilon_2}; (12)$$

where $^q \approx \delta \cdot q \; ; q \; ^q \vDash$ and is a constant. Then the minimax threshold l_n should be the value that satisfy

$$E \qquad cq* \; ^q \qquad _{2;n} L*^n 1(\varepsilon_{22}\dots \vDash X_{ni} \, ^n 1 \min q_{2i} \; ;^{\varepsilon} 2) \text{ for all } q \; 2$$

$\approx$

$$\approx \delta q \; ; q \qquad q \vDash \qquad\qquad (13)$$

Hence, (9) and (10) that satisfy condition (12) and (13) are the key tools for identifying the threshold benchmark of change points.

5. Result and discussion

5.1. Empirical result

As shown in Fig. 2, it is not apparent to observe all the change points from raw historical data. In order not to overlook any information, we would examine all change points via the minimax threshold (13) and via the fix point threshold (7), and then compare their features and characteristics. Afterwards, we make reference to historical events that correspond to the detected changes. This is followed by a discussion on the location effect and on the spreading out effect among the four cities under study (see Fig. 3).

5.2. Discussion on the change points

As minimax threshold selection rules are more aggressive and would be more convenient to apply than Ip's method (2004), when small details of the signal lie near the noise range. Thus, the following section discusses the findings based on the minimax threshold.

(1) The change points of the first series of Singapore's real estate prices are observed around 1999 (Table 3). It is reported that home prices fell by 17% in the first quarter of 1998, and real estate stocks fell from the effects of the oversupply of new apartments, condominiums, and houses, which resulted in a decrease of the valuation of 16 property stocks by 39%. However, on June 16th, the property index fell to its lowest in five and a half years. Later in the same month, government unveiled some stimuli, basically to resume the sales of all housing and commercial land throughout 1999, and increased the property tax rebate from 15% to 55%.

(2) Following 9/11, economic recession widely spread globally, and it is expected that Asia could have suffered immensely from it. Much to our surprise, however, only Singapore is detected to have had some abrupt changes at that moment, whilst the other three cities remained stable. The detected change points imply that Singapore suffered the deepest recession in the past four decades, during which time the unemployment rate rose to its highest in 15 years. 10 million square feet of office spaces were left vacant. House price, office price, and rent dropped dramatically. In contrast, similar economic policies specifically for housing or economic crises were not found among the other three cities.

(3) The change points for the residential real estate price index of Shanghai are detected from 2002Q4 to 2003Q2 (Table 3). The changes reflect the outbreak of epidemic of Severe Acute Respiratory Syndrome (SARS) during that period. This unknown disease lasted for 10 months and resulted in
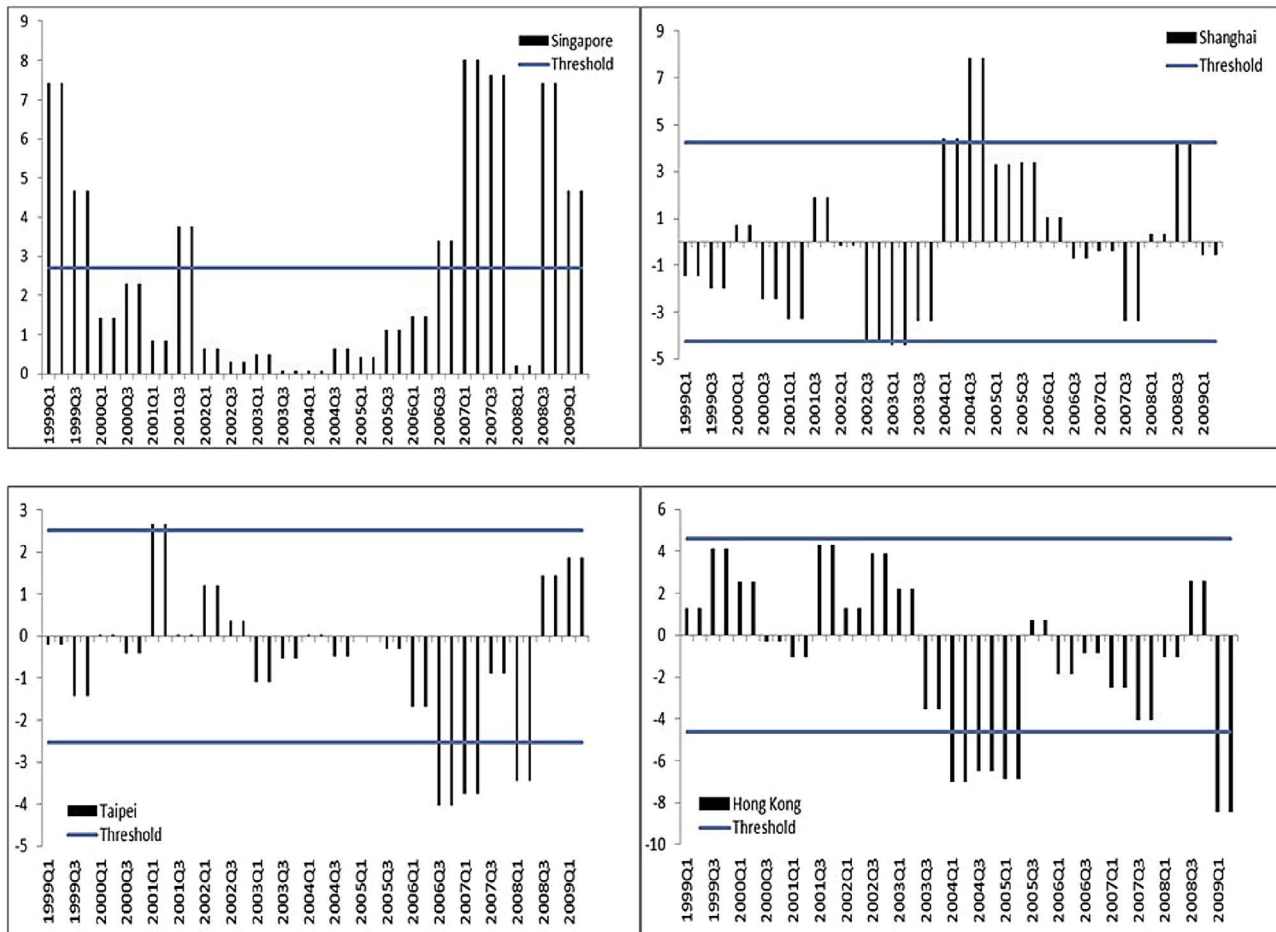

Fig. 3. Coefficient plot of minimax threshold of the four Asian cities.

Table 3
Change point by minimax threshold.

Time	Singapore	Taipei	Shanghai	Hong Kong
1999Q1~1999Q4	√			
2001Q1~2001Q2		√		
2001Q3~2001Q4	√			
2002Q3~2003Q2			√	
2004Q1~2004Q4			√	√
2005Q1~2005Q2				√
2006Q3~2007Q2	√	√		
2007Q3~2007Q4	√			

approximately 4 billion US dollar of economic loss. To some extent, it is believed that there should be some significant

(5) negative impact on the residential market. On the contrary, the real situation did not turn out as expected, as more investors chose to invest in the Shanghai real estate market to hedge against financial risks. Hence, the time series plot of the residential price index of Shanghai exhibited an upward trend during that period (Fig. 2).

(6) (4) The Severe Acute Respiratory Syndrome (SARS) had relentlessly attacked Hong Kong. In late 2003, the Government finally controlled the spread of SARS and issued some policies to stimulate the economy. With investors' confidence recuperated, the real estate market of Hong Kong regained momentum. A series of detected change points can be seen in Table 3 around year 2004. At about the same time, another series of change points are also detected in Shanghai. Unfortunately, the causes of these change points differ between the two cities. For Shanghai, since more and more investors became aware of the potential overheating of the residential market after the SARS event, they even finance their purchases through mortgages from commercial banks or other financial institutes, thus further overheating Shanghai's real estate market in the process. To avoid such a predicament, the Chinese Central Government launched a series of macroeconomic adjustments, such as "Circular of the General Office of the State Council on Effectively Stabilizing House Prices" and the withdrawal of favorable mortgage policies in attempt to maintain a stable environment for the development of the real estate market.

When the unexpected news of the bankruptcy of the Lehmann Brothers' Company broke in mid-Sep 2008, the global economic and financial climate dramatically fell to the bottom and inhabited the recession cycle. The change points between 2009Q1 and 2009Q2 primarily illustrate such severities in Singapore and in Hong Kong. The new restriction on the use of CPF in the purchase of the second apartment (Jul 2006) caused a change point and appeared to slow down the upward trend of property price a little. However, the international property market expansion (as seen in Taipei and in Hong Kong at the same time) offset the impact of restriction soon. In 2007, the housing price rose up again and new significant change points were detected.

5.3. Comparison with CUSUM test

In the previous section, we present the wavelet analysis in the detection of change points, which is more powerful and sensitive. To strengthen this notion, the CUSUM test, a popular change point test widely used in previous studies for statistical control, is carried out for comparison. The result is summarized in Table 5. By comparing Tables 3 and 5, it is apparent that the wavelet change point technique is much more sensitive than CUSUM test. Thus, in the following sections, the analysis is carried out through considering wavelet change point (see Fig. 4).

5.4. Key findings

It is apparent that the wavelet detection technique with a minimax threshold is even more sensitive than that with a fixed point threshold (for example, hard threshold). These detected change points are related to economic adjustments or the implementation of fiscal policies. From the previous section, the wavelet coefficients are separated into two parts, namely the "killed" and "kept" proportions. To facilitate our analysis, only those greater than the minimax threshold value are retained (Table 3). We suppose that the "kept" ones are the signals implied to have a longterm effect on the related market, and hence the coefficients for these change points (Table 3) should last for at least two consecutive quarters. In other words, the longer the event sustains, the more powerful influence on the market it has, since a jump in the above function results in several non-zero coefficients adjacent to each other (Ogden and Parzen, 1996). From Table 3, the period between 2003Q3 and 2004Q4 in Shanghai is the longest among all the change point series that covered events, such as the outburst of SARS and various macroeconomic adjustments in Mainland China during that time. The second longest series of change points occurred in Hong Kong between 2004Q1e2005Q2, and in Singapore between 2006Q3e2007Q4. Hong Kong did not begin to recover until the real estate market reached its bottom by the end

Table 4A
Partial Correlation coefficients between Shanghai and Hong Kong.

Table 5
Change point by CUSUM Test.

Time	Singapore	Taipei	Shanghai	Hong Kong	
				√	2002Q3~2003Q2
	√	√	√		2004Q1~2004Q4
2007Q3~2007Q4					
2008Q1~2008Q2					
2008Q3~2008Q4	√	√	√		
2009Q1~2009Q2					

Note: The symbol "√" indicates that an abrupt change point happen during the corresponding period.

of 2003. On the other hand, the significant changes occurred in Singapore are mainly due to the volatility in the financial market. In Feb 2006, the price of luxury residential properties rose by about 5e10%, due to strong demand from overseas companies, and the Straits Times Index rose to its highest in six years. Moreover, in Dec 2006, the Straits Times Index further rose to a record high due to the recovery of the housing market in the U.S.

As mentioned in the first section, we intend to check whether there is a spreading out effect relationship between the four Asian cities. A general opinion is that the real estate markets in developed cities, such as Hong Kong and Singapore, should be more stable than those in less developed ones. That means the large number of change points and the frequent abrupt changes should exist mainly in the housing markets of developing cities (Shanghai). In the comparison of the change points among the selected cities in Table 3, three special features coincide with our expectation. As the correlation between Singapore and Taipei housing markets is approximately 0.88737, it is clear that the characteristics of these two cities are very similar (Fig. 2). It is thus not hard to conclude why the detected changes of these two cities mainly fall within the period between 2006Q3 and 2009Q2. On the contrary, the timeseries plot between Shanghai and Hong Kong look very different (Fig. 2). During the period between 2000Q1 and 2004Q1, the Shanghai and Hong Kong markets developed towards two different directions, and their resultant correlation was negative (0.6944). Nonetheless, the correlation between them increased to 0.6011 during the period from 2005Q3 to 2009Q2 (Table 4A). We suppose that Shanghai initially took the lead when SARS broke out in late 2002. Having experienced the effect of the SARS epidemic which lasted five quarters, the fluctuations of the Shanghai residential

	Hong Kong (2000Q1~2004Q1)	Hong Kong (2005Q3~2009Q2)
Shanghai (2000Q1~2004Q1)	0.6944	
Shanghai (2005Q3~2009Q2)		0.6011

Table 4B

Partial correlation coefficients with different time lags.

Taipei and Hong Kong			
	$x_{Hong\ Kong;\ 2008Q1}$	$x_{Hong\ Kong;\ 2008Q2}$	$x_{Hong\ Kong;\ 2008Q3}$
$x_{Taipei;\ 2008Q1}$	0.17546	0.30524	0.74261*
Taipei and Shanghai			
	$x_{Shanghai;\ 2008Q1}$	$x_{Shanghai;\ 2008Q2}$	$x_{Shanghai;\ 2008Q3}$
$x_{Taipei;\ 2008Q1}$	0.07264	0.65189	0.98232*
Taipei and Singapore			
	$x_{Singapore;\ 2008Q1}$	$x_{Singapore;\ 2008Q2}$	$x_{Singapore;\ 2008Q3}$
$x_{Taipei;\ 2008Q1}$	0.42596	0.18767	0.78523*

Note: the number labeled asterisk in the table show that Taipei is strong negative linear correlated with any of the other three Asian residential real estate markets two periods lag behind.
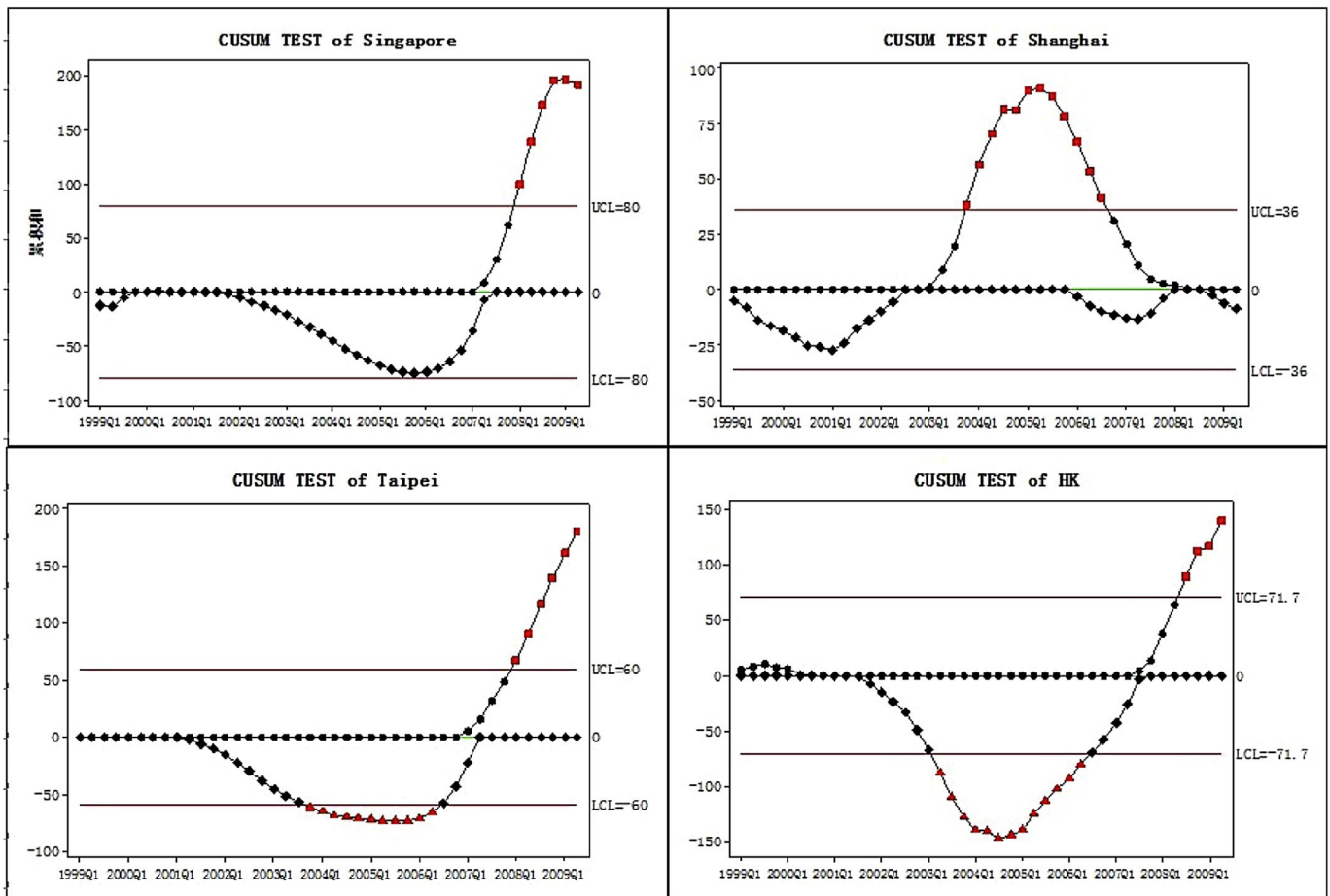
Fig. 4. Data plot of CUSUM test for the four cities.

market slowly "infected" the Hong Kong residential market. Moreover, between 2008Q1 and 2009Q2, there was a spreading out effect among all four Asian cities (Table 4B). The first two change points that appeared in Taipei city (2008Q1eQ2) are seen as the fountainhead of this effect, due to the U.S. Subprime Crisis in early 2008, regarded as the recession signals for the real estate market and for the economy. Then the shock diffused into Singapore and Shanghai in 2008Q3eQ4 and finally transmitted to other Asian cities in 2009Q1eQ2. By examining those change points more carefully (Table 4A), it is worth mentioning that the distribution of the change points depicts a spreading out effect relationship. Of course, this phenomenon did not just happen by chance. The major reason behind this is the strong relationship between real estate markets and financial markets as well as credit markets in Asian cities. Therefore, it is not hard to explain why the effect of economic recession and financial crises will soon spread to the real estate market.

6. Conclusion

The Wavelet analysis is renowned to be a new and powerful tool in many disciplines for the purpose of jump point detections. However, it has been rarely used in real estate researches. To fill in this gap, this paper has detected abrupt change points in residential housing prices by using wavelet analysis with the minimax threshold technique, and then further analyzed the relationship between these detected change points and the corresponding policies as well as economic crises. Compared with traditional structural change point detection methodologies that rely on a large sample data sets, the wavelet analysis only requires a small data set, which is suitable for investigating the emerging real estate markets in which only recent data is available (for example, Shanghai).

The findings show that structural change points are indeed detected for the four Asian cities (Singapore, Hong Kong, Taipei and Shanghai), which usually appeared in the aftermath of political events, economic crises, or epidemic disease. A detected change point, using the minimax threshold, can best identify both upturn and downturn signals for investors. It may imply that there is a significant increase (or drop) at that point in the market, which suggests that the investors take action in response. Surprisingly, on calculating the partial correlations between Shanghai and Hong Kong as well as between Taipei and the other three real estate markets (Tables 4A and B), a spreading out effect relationship between the four Asian real estate markets are discovered. In 2008Q1e2009Q2, Taipei was seen as the fountainhead of this spreading out effect due to the U.S. Subprime Crisis of early 2008, and then transmitted the shock to other Asian cities in 2009Q1eQ2 as the bankruptcy of Lehmann Brothers' triggered the financial tsunami in late 2008. This is likely to be the evidence showing that economic recession and financial crises would soon pass onto the real estate market.

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References

Andrew, M., & Meen, M. (2003). House price appreciation, transactions and structural change in the British housing market: a macroeconomic perspective. Real Estate Economics, 31(1), 99e116.

Bourassa, S. C., Haurin, D. R., Haurin, J. L., Hoesli, M., & Sun, J. (2009). House price changes and idiosyncratic risk: The impact of property characteristics. Real Estate Economics, 37(2), 259e278.

Canarella, G., Miller, S., & Pollard, S. (2012). Unit roots and structural change: an application to US house price indices. Urban Studies, 49(4), 757e776.

Donoho, D. L., & Johnstone, I. M. (1994). Ideal spatial adaptation by wavelet shrinkage. Biometrika, 81(3), 425e455.

Eubank, R. L., & Speckman, P. L. (1995). Nonparametric estimation of functions with jump discontinuities. In Ed E. Carlstein, H. G. Mueller, & D. Siegmund (Eds.), Change point problems, Proceedings of the Mount Holyoke Conference. Hayward, Califonia: Institute of Mathematical Statistics.

Falkenbach, H. (2009). Diversification benefits in the Finnish commercial property market. International Journal of Strategic Property Management, 13(1), 23e35.

Haight, G., & Singer, D. (2005). The real estate investment handbook. New Jersey: J. Wiley.

Hansen, B. E. (2001). The new econometrics of structural change: Dating breaks in U.S. labor productivity. The Journal of Economic Perspectives, 15(4), 117e128.

Hillebrand, E., & Schnabl, G. (2006). A structural break in the effects of Japanese foreign exchange intervention on yen/dollar exchange rate volatility. In Working paper series, No 650. European Central Bank.

Hui, E. C. M., Lau, O. M. F., & Lo, K. K. (2009). A fuzzy decision-making approach for portfolio management with direct real estate investment. International Journal of Strategic Property Management, 13(2), 191e204.

Hui, E. C. M., Liang, C., Ip, W. C., & Ho, D. K. H. (2013). Examining structural changes in Asian offices market. Land Use Policy, 32, 375e380.

Hui, E. C. M., Liang, C., Zhong, J., & Ip, W. C. (2015). Structural and policy changes in the Chinese housing market. Journal of Urban Planning and Development, 142(1), 04015012, http://dx.doi.org.eproxy1.lib.hku.hk/10.1061/(ASCE)UP19435444.0000294. Source: http://ascelibrary.org.eproxy1.lib.hku.hk/doi/abs/10. 1061/(ASCE)UP.1943-5444.0000294.

Hui, E. C., Wang, Z., & Wong, H. (2014). Risk and credit change in Asian securitized real estate market. Habitat International, 43, 221e230.

Hui, E. C. M., & Yu, K. H. (2012). Assisted homeownership, investment and their roles in private property price dynamics in Hong Kong. Habitat International, 36(2), 219e225.

Hui, E. C. M., Yu, C. K. W., & Ip, W. C. (2010). Jump point detection for real estate investment success. Physica A: Statistical Mechanics and Its Applications, 389, 1055e1064.

Inoue, A. (1999). Tests of cointegrating rank with a trend-break. Journal of Econometrics, 90(2), 215e237.

Ip, W. C., Wong, H., Xie, Z., & Luan, Y. (2004). On comparison of jump point detection for an exchange rate series. Science in China Series A Mathematics, 47(1), 52e64.

Johansen, S., Mosconi, R., & Nielsen, B. (2000). Cointegration analysis in the presence of structural breaks in the deterministic trend. Econometrics Journal, 3, 216e249.

Lai, K. K., & Huang, J. (2007). The application of wavelet transform in stock market. Conference Paper published in http://www.jaist.ac.jp/library/jaistpress/index. html.

Lavielle, M., & Teyssiere, G. (2006). Detection of multiple change-points in multivariate time series. Lithuanian Mathematical Journal, 46(3), 287e306.

Ling, Z., & Hui, E. C. (2013). Structural change in housing submarkets in burgeoning real estate market: a case of Hangzhou, China. Habitat International, 39, 214e223.

Lombard, F. (1988). Detecting change points by Fourier analysis. Technometrics, 30, 305e310.

Malpezzi, S., & Wachter, S. M. (2005). The role of speculation in real estate cycles. Journal of Real Estate Literature, 13(2), 141e164.

Meen, G. (2002). The time-series properties of house prices: a transAtlantic divide? Journal of Housing Economics, 11, 1e23.

Muller, H. G. (1992). Change-points in nonparametric regression analysis. Annals of Statistics, 20(2), 737e761.

Nguyen, T. B., van der Krabben, E., & Samsura, D. A. A. (2014). Commercial real estate investment in Ho Chi Minh CityeA level playing field for foreign and domestic investors? Habitat International, 44, 412e421.

Ogden, T., & Parzen, E. (1996). Change-point approach to data analytic wavelet thresholding. Statistics and Computing, 6(2), 93e99.

Rachev, S. T., & SenGupta, A. (1993). Laplace-Weibull mixtures for modeling price changes. Management Science, 39(8), 1029e1038.

Strikholm, B. (2006). Determining the number of breaks in a piecewise linear regression model. In SSE/EFI working paper series in economics and finance, No 648.

Tse, R. Y. C. (2001). Impact of property prices on stock prices in Hong Kong. Review of Pacific Basin Financial Market and Policies, 4(1), 29e43.

Tu, Y., & Bao, X. H. (2009). Property rights and housing value: The impacts of political instability. Real Estate Economics, 37(2), 235e257.

Vuorenmaa, T. A. (2005). A wavelet analysis of scaling laws and long-memory in stock market volatility. Bank of Finland Research Discussion Papers, 27.

Wang, Y. (1995). Jump and sharp cusp detection by wavelets. Biometrika, 82(2), 385e397.

Worzala, E., & Sirmans, C. F. (2003). Investing in international real estate stocks: A review of the literature. Urban Studies, 40, 1115e1149.

Xie, Z. (1993). Case studies in time series analysis. Singapore: World Scientific.

Yin, Y. Q. (1988). Detection of the number, locations and magnitudes of jumps. Communications in statistics. Stochastic Models, 4(3), 445e455.