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Is there Long-Run Equilibrium in the House Prices of Australian Capital Cities?

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In order to explore the long-run equilibrium in the house prices of different cities, studies on house price convergence have been conducted by a number of researchers. However, the majority of previous studies have neglected the effects of spatial heterogeneity and autocorrelation on house prices. This research improves on the investigation of house price convergence by developing a spatio-temporal autoregressive model based on a framework of panel regression methods. Both spatial heterogeneity and autocorrelation of house prices in different cities are taken into account. Geographical distance and the scale of development of the urban housing market are used to construct temporal varying spatial measurements. The spatio-temporal model is then applied to investigate the long-run equilibrium in the house prices of Australian capital cities. The results confirm that house prices in Sydney approach a steady state in the long run, whereas house prices in Brisbane, Canberra, Melbourne and Perth are able to do with lower confidence. However, little evidence supports the existence of long-run equilibrium in the house prices of Adelaide, Darwin and Hobart.

Keywords

Convergence, Spatial Autocorrelation, Spatio-Temporal Regressive Model, Long-Run Equilibrium, House Price Indices, Australia

1. Introduction

Studies on house price convergence have investigated the equilibrium of house prices in the long run. They have addressed the question of whether house prices in different regions can move towards one or several steady states. The long-run equilibrium in house prices across a country is important because it reflects the stability of the regional house markets. The long-run equilibrium in the house prices of various nations has been previous studied. However, the capital cities in Australia have distinct differences, from geography, demography and economy to social culture, which subsequently make the housing markets in the Australian capital cities different from each other. It is important to investigate whether the long-run equilibrium in the house prices of these cities appears to be important to the government in producing proper housing policies that would reduce the level of inter-regional imbalance in housing, to investors in more accurately simulating and predicting housing market movements, and to individuals in protecting their assets. However, previous research on the house prices in the Australian capital cities have neglected these spatial effects and therefore failed to obtain comprehensive results.

A typical housing market is composed of not only the segmentation of sub-markets, but also their interconnectedness which leads to ripple effects in the house prices (Meen 1996). These two factors cause concern about house price convergence. Due to the use of unit root tests for house prices, investigations on house price convergence are therefore based on consistent gaps or different ratios between regional house prices and a benchmark, such as a national house price or the house price in a dominant region. If a different ratio for the convergence is found, then the regional house prices in a nation will move towards a steady state, which can be reflected through the use of a vector. A study on long-run equilibrium relationships or convergence between regional housing prices has been undertaken by MacDonald and Taylor (1993), but their findings fail to prove that regional house prices in the UK have converged to a steady state. Drake (1995) has conducted a formal test on the convergence of regional house price ratios in the UK. Once again, no strong evidence is found to support the convergence of the different ratios of house price. A time-series testing method, which is the so-called “stationary test” or “unit root test”, has been widely used to investigate the convergence of house price ratios. Cook (2003) argues that a limitation of this method has led to the failure to reveal convergence. As an alternative method, Cook (2003) proposes an asymmetric unit root test to find the convergence of different house price ratios. Pair-wise convergence of regional house price ratios in the UK is investigated by using an asymmetric method, although the research evidence does not strongly demonstrate that there is convergence. Liu et al. (2009) conduct variance decomposition based on a structural vector autoregressive (VAR) model to investigate the ripple effects of regional house prices in Australia. They find significant evidence to support the interdependence of house prices across Australian capital cities.

It is accepted that the variables in time-series regression modeling are required to be stationary. Non-stationarity and spatial heterogeneity of regional house prices may cause unreliable results as house prices are not stationary at levels. This implies the possibility of non-stationary ratios of house prices and therefore, it is difficult to find convergence by using time-series methods. Holmes (2007) proposes an innovative approach to investigate the convergence in the house price ratio by employing unit root tests within a panel regression framework. This panel unit root model considers heterogeneity in the steady state as well as in the regional rates of convergence. In the same study, the panel unit root test was applied to regional house prices in the UK, where the findings concluded that the panel regression model is more robust than a purely time-series based model (Holmes 2007). This research also demonstrates that the convergence of house price ratios is detected in most regions of the UK. The panel unit root tests are subsequently improved by using the first principal component (Holmes and Grimes 2008).

Ma and Liu (2010) propose the decomposing of three-dimensional panel data sets of house prices under a panel regression framework. They demonstrate that a change in the regional house prices are influenced by specific regional, and local market and neighbouring market factors. They apply this dynamic panel model to the housing markets of Australian capital cities, and find that there is spatial heterogeneity across the regional housing markets. Holly et al. (2010) examine the cointegration between house prices and the fundamental factors at the state level in the USA. Their findings indicate spatial effects on house prices. Subsequently, a temporal and spatial model is developed to investigate the house price diffusions across cities in the UK. Both temporal and spatial effects on house prices are taken into account by using a spatio-temporal diffusion model. However, the spatial weights used by this research are purely constructed based on geographical information, which is assumed to remain unchanged over the observation period.

This research will add to the current literature in two ways. First, instead of investigating the convergence of house price ratios against a benchmark, this research will explore the long-run equilibrium in the house prices of different cities. Second, a spatio-temporal regression model is developed to examine house price convergence with spatial autocorrelation. It is assumed that spatial effects on regional house prices should vary along the temporal dimension, as the regional housing market changes from time to time. In order to simulate the temporal variations of spatial effects on house prices, this research will use the size of the regional housing market and geographical information for the construction of spatial weights. The remainder of this paper is organised as follows: the following section provides the theories and methodologies for a spatio-temporal regression model for house price convergence and the construction of the temporal variation of the spatial measurements. The third section describes the related data in the Australian capital cities. The fourth section reports the empirical results of house price convergence in the Australian capital cities. The final section concludes.

2. A Spatio-Temporal Regression Model for House Price Convergence

Spatio-temporal regressive models are derived from the framework of spatial panel regression models, which contains both spatial and temporal lags, thus allowing for model disturbances to be mutually correlated both spatially and temporally (Beenstock and Felsenstein 2007; Fingleton 2008).

2.1 House Price Convergence Model

The long-run equilibrium relationships in the house prices of a region can be investigated by using a spatio-temporal regressive model, which is expressed as follows:

$$\Delta p_{it} = \alpha_i + \beta_i p_{i,t-1} + \rho_i \Delta p_{i,t-1} + \gamma_i \Delta p^{w}_{i,t-1} + u_{it} \tag{1}$$

where p_{it} is the logarithm value of the house price in region i at time period t. The model can be used to determine whether the house price changes in region i, p_{it} will converge to a steady state $f(\alpha_i, \beta_i)$ over the whole observed period. The rate of convergence, denoted by β_i, indicates the rate that individual regional housing markets will move towards a steady state. This model also assumes that house price differentials are also influenced by both temporal lags, $\Delta p_{i,t-1}$ and spatio-temporal lags $\Delta p^{w}_{i,t-1}$.

Based on Eq.(1), the house prices would follow the concept of club convergence, which means that house prices in different areas converge towards individual steady states through different paths, rather than sharing the same steady state and convergence process. This means that regional house prices will converge together, but only if these regional housing markets have similar structures and initial conditions. With this understanding, the Australian regional house prices will converge to their own steady states. According to the regional characteristics, the steady states for the house prices of cities may be attained through specific paths that depend on the initial conditions. As a result, if convergence clubs exist, a city where the initial price level is further from a steady state may have a relatively higher growth in house price.

In order to simulate and predict the performance of the regional housing markets, Eq.(1) can also be seen as a system of equations that needs to be simultaneously solved, and expressed as follows:

$$\Delta P_t = A + BP_{t-1} + \Gamma \Delta P_{t-1} + U_t \tag{2}$$

where $P_t = (p_{1t}, p_{2t}, \cdots, p_{Nt})'$, $A = (\alpha_1, \alpha_2, \cdots, \alpha_N)'$, $U_t = (u_{1t}, u_{2t}, \cdots, u_{Nt})'$, $B = \begin{bmatrix} \beta_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \beta_N \end{bmatrix}$, $\Gamma = \begin{bmatrix} \rho_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \rho_N \end{bmatrix} + \begin{bmatrix} \gamma_1 W_1' \\ \vdots \\ \gamma_N W_N' \end{bmatrix}$, and $W_i = (w_{i1,t}, w_{i2,t}, \cdots, w_{iN,t})'$.

Eq.(2) presents a system of vector autoregressions with spatial lags in the regional house prices. This model can also be written as a spatio-temporal generalised VAR model, and expressed as follows:

$$P_t = A + \Pi_1 P_{t-1} + \Pi_2 P_{t-2} + U_t \tag{3}$$

where $\Pi_1 = (B + \Gamma + I_N)$, $\Pi_2 = -\Gamma$. The temporal dependence of regional house prices is captured by the coefficient matrices Π_1 and Π_2 . The spatial dependence is captured by the covariance of the error term U_t, $Cov(u_{it},\ u_{jt})$ with $i \neq j$. The temporal coefficients Π_1 and Π_2 are affected by the spatial dependence of regional house prices. This spatial dependence is constrained by the non zero values of w_{ij}. Subsequently, the impulse response functions based on Eq.(3) can be used to interpret the temporal and spatial interconnections among regional house prices.

Impulse response functions are widely used to simulate and predict the movement of variables traditionally in the econometrics field. Impulse responses based on a vector autoregressive model indicate dynamic effects on each variable when a shock is injected into the system. Accordingly, a system can be characterised by plotting the impulse response functions (Greene 2002). The impulse responses of the model can be used to simulate the spatial-temporal dynamic effects of innovations on the variables. However, this is more complex than with the conventional VAR as shocks propagate across cities as well as over time (Beenstock and Felsenstein 2007). By denoting $\Gamma = A + \Pi_1 + \Pi_2$, and L as the lagged operator, Eq.(3) can be rewritten as:

$$P_t = (I - \Gamma L)^{-1} U_t \tag{4}$$

Since Γ is dependent on W, the response of the model under an innovation in D will depend on the spatial lag coefficients, C. In the model construct, a given shock directly affects the house price in the same region, while influencing the house prices in other cities through spatial lag terms. Therefore, the shock of the house price in one city is transmitted to the neighbouring housing markets in the following period, weighted by W. The variance-covariance is expressed as follows:

$$\Sigma = E(\varepsilon_i \varepsilon_j^{'}) = \begin{bmatrix} \sigma_{11}^2 & \sigma_{12}^2 & \cdots & \sigma_{1N}^2 \\ \sigma_{21}^2 & \sigma_{22}^2 & \cdots & \sigma_{2N}^2 \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{N1}^2 & \sigma_{N2}^2 & \cdots & \sigma_{NN}^2 \end{bmatrix} \quad (5)$$

where$\sigma_{ij}^2 = cov(\delta_{it}, \delta_{jt})$, and ε_i is an $N \times 1$ vector with a unit vector in the ith element and zero in the others.

The dynamics of the regional house prices during the period of prediction can be derived from a generalised impulse response function (Pesaran and Shin 1998) as follows:

$$\Delta p_{is}^* = \frac{\Psi_s \Sigma g_s}{\sigma_{ij}}, \Psi_s = \Gamma \Psi_{s-1}, \text{with } \Psi_0 = I_N \quad (6)$$

Although spatial effects have been considered in the aforementioned model to analyse the convergence of house prices, the model is still confined to interpreting convergence in discrete time periods. Therefore, with the application of panel data regression, we can capture the convergence characteristics of house prices for a continuous and long running period of time. As can be observed from Eq.(1), the estimated constant coefficients and the coefficients of the house prices indicate the steady states and the rate of convergence. Moreover, the coefficients of the temporal and the spatial lags can explain for the magnitude of the regional house price growth influenced by temporal and spatial effects. By using different pre-assumptions, the modeling can be categorised into three types of models, namely, the absolute regional, conditional regional and regional club convergence models.

2.2 Temporally Varied Spatial Measurements

Although spatio-temporal analysis perform better than a pure temporal and spatial analysis, one controversial issue is how to measure the potential interaction between two spatial units. As discussed before, there are many ways of constructing spatial weight matrices. The original suggestion was to use a combination of distance measures and the relative length of the common border between two spatial units. This method tends to be less relevant; however since boundary length and area are largely artificial as the spatial interactions are determined by factors which have little to do with the spatial configuration of boundaries on a physical map (Anselin 1988).

Consequently, the construction of a spatial weight matrix must be tightly correlated with the particular situation under study. Besides the distances between geographical locations, the developing size of housing markets must also be taken into account for the spatial effects. In this research, the market scales are assumed to be recognised as an important indicator that represents the spatial information of the regional markets. It is anticipated that the neighbouring markets that are relatively larger in scale should result in more significant spatial effects on the local housing market than those that are smaller in scale. With this in mind, this research uses regional new dwelling unit numbers to represent the scale of the development of the housing market. Moreover, the two types of distance (geographical and the scale of the development of the urban housing market) described by previous research are combined with the scale of the housing market to propose hybrid spatial weight matrices, known as geographical and demographical hybrid spatial weights respectively in this research. The geographical hybrid weight (GH-weight) is expressed as follows:

$$w_{ij,t} = d_{ij}^{-1} \times \frac{nod_{jt}}{nod_{it}+nod_{jt}} \quad (7)$$

where d_{ij} denotes the distance between cities i and j, and nod_{it} stands for the new dwelling unit number for city i at time t. The spatial weights are larger for closer or neighbouring markets with a larger number of dwelling units, but smaller for farther or neighbouring markets with a smaller number of dwelling units.

3. Description of Related Data in Australian Capital Cities

3.1 Scale of Housing Markets in the Australian Capital Cities

The house price indices and approved number of new houses in Australian capital cities are published by the Australian Bureau of Statistics (ABS 2013a; 2013b). The observation period for the research is from Q1 in 1993 to Q4 in 2012. The data show the monthly details of building work approved in the Australian capital cities (ABS 2013a). Statistics of approved building works are compiled from permits issued by local government authorities and other principal certifying authorities, contracts let by commonwealth, state, semi-government and local government authorities and major building approvals in areas not subject to normal administrative approval. This data set focuses on the scales of change for the housing market in each capital city. The original monthly data are converted into quarterly data by summarising the numbers every three months. Table 1 shows the basic statistics for the number of dwelling units during the observation period, including the quarterly average numbers, the maximums, the minimums and the standard deviations.

It can be observed that Melbourne has the largest scale of development over the entire observation period. The average number of new houses in Melbourne is over 5129 in each quarter, followed by Perth and Sydney, with 3057 and 2741 new housing approvals respectively. Brisbane is on a similar scale with Sydney, while Adelaide ranks fifth with almost half the number of new houses that are found in Brisbane. Melbourne also has the highest maximum, minimum and standard deviation. This suggests that the housing market development in Melbourne is fast and fluctuating. The scale of housing development in Brisbane and Perth has also quickly increased, but is more stable compared to that of Melbourne and Sydney. The quarterly approved number of new houses in Hobart, Darwin and Canberra is very small: 122, 222 and 351 respectively, thus indicating that the smallest residential housing markets are in these capital cities. The large differences in the scale of the housing market development indicates that the spatial heterogeneity of house prices across cities may also depend on the scale of the housing markets. The spatial weights of the house prices will be constructed by using regional housing market differences.

This research uses the augmented Dicky-Fuller (ADF) unit root test (Dicky & Fuller 1979) to identify the stationarity of the house prices. Table 2 shows the unit root test results of the eight capital cities.

The null hypothesis of the non-stationarity is performed at the 1% and 5% significance levels. There are three different null hypotheses of the time series processes in this test: process as a random walk, process as a random walk with drift, and process as a random walk with drift around a deterministic trend. These are shown in Table 2 respectively: no trend and intercept, intercept without trend and, intercept and trend. The results show that data series of the house price indexes of the eight capital cities are not stationary at the level form but stationary after the first difference at the 1% and 5% significance levels. That is, all eight data series are integrated at the first difference.

3.2 Temporal Variation of Spatial Weights

By incorporating the distances between pairs of capital cities and the quarterly approved number of new houses, the spatial weights of the capital cities that vary with time are calculated at each time point by using Eq.(7). The temporal averages of the spatial weights are reported in Table 3. The temporal averages of the spatial weight of housing prices do not have large differences, which range from 0.0389 to 0.0941. It can be observed that Melbourne often accounts for the relatively higher spatial weights compared to the housing markets in the other capital cities, mainly due to its centrality in location and housing market that is large in scale. The smaller scale in the development of the housing market in Darwin and its remote location have led to relatively low spatial weights in comparison to the housing markets in the other capital cities

Table 1 Descriptive Statistics for the Number of Dwelling Units in Australia's Capital Cities

	Mean	Minimum	Maximum	Std. Dev.
Adelaide	1338.75	698	2007	308.41
Brisbane	2713.32	1646	4024	540.01
Canberra	351.42	179	627	106.42
Darwin	122.76	46	289	45.08
Hobart	222.36	87	365	67.54
Melbourne	5129.24	2524	7105	1030.91
Perth	3057.04	1826	4127	560.69
Sydney	2741.47	1322	4650	928.62

Table 2 Unit Root Test Results for House Price Indices of Australian Capital Cities

		ADF test at level			ADF test at first difference		
		P-value	Sig. level	Lag	P-value	Sig. level	Lag
No intercept and trend	**Adelaide**	0.9573	na	2	0.0329	**	1
	Brisbane	1.0000	na	0	0.0221	**	1
	Canberra	0.9639	na	1	0.0084	***	0
	Darwin	0.9987	na	1	0.0058	***	1
	Hobart	0.9689	na	1	0.0195	**	0
	Melbourne	0.9788	na	2	0.0214	**	1
	Perth	0.9679	na	3	0.0731	*	2
	Sydney	0.9607	na	1	0.0018	***	0
Intercept without trend	**Adelaide**	0.6969	na	2	0.0963	*	1
	Brisbane	0.9956	na	0	0.0000	***	0
	Canberra	0.9354	na	1	0.0342	**	0
	Darwin	0.9989	na	1	0.0136	**	1
	Hobart	0.9177	na	1	0.0573	*	0
	Melbourne	0.9703	na	2	0.0508	*	1
	Perth	0.9950	na	0	0.1706	na	2
	Sydney	0.9540	na	1	0.0107	**	0
Intercept with trend	**Adelaide**	0.7586	na	2	0.2795	na	1
	Brisbane	0.3208	na	0	0.0878	*	1
	Canberra	0.5770	na	1	0.1178	na	0
	Darwin	0.1330	na	2	0.0001	***	0
	Hobart	0.5936	na	1	0.2036	na	0
	Melbourne	0.9593	na	0	0.1237	na	1
	Perth	0.9936	na	0	0.0001	***	0
	Sydney	0.3285	na	1	0.0326	**	0

Table 3 Average Temporal Variation of Spatial Weights

	Adelaide	Brisbane	Canberra	Darwin	Hobart	Melbourne	Perth	Sydney
Adelaide	0.0000	0.0605	0.0553	0.0438	0.0540	0.0712	0.0593	0.0633
Brisbane	0.0549	0.0000	0.0517	0.0409	0.0471	0.0616	0.0536	0.0629
Canberra	0.0682	0.0703	0.0000	0.0481	0.0614	0.0795	0.0625	0.0856
Darwin	0.0663	0.0680	0.0589	0.0000	0.0567	0.0700	0.0671	0.0669
Hobart	0.0724	0.0696	0.0667	0.0503	0.0000	0.0941	0.0650	0.0740
Melbourne	0.0599	0.0571	0.0542	0.0389	0.0591	0.0000	0.0530	0.0616
Perth	0.0530	0.0528	0.0453	0.0397	0.0434	0.0563	0.0000	0.0531
Sydney	0.0577	0.0632	0.0633	0.0404	0.0503	0.0667	0.0541	0.0000

3.3 Spatial Autocorrelation of Urban House Prices

Spatial autocorrelations in this study measure the interrelationship between housing prices in different cities. The statistical method used to test the existence of spatial autocorrelations is the Moran's I test, and its null hypothesis means that there is no relation between housing prices in different capital cities and their relative weights (Moran 1950). The Moran's I values range from -1 to 1. A positive Moran's I value indicates the clustering of similar housing prices, while a negative value indicates the tendency for dissimilar housing prices to cluster. When the Moran's I value is close to 0, the physical distribution of housing prices follows a random distribution, which indicates the lack of spatial autocorrelation.

The results of the Moran's I tests for housing prices in the Australian capital cities and the corresponding Z-scores are shown in Figure 1.

The Moran's I values are negative, which suggest that the movement of housing prices among the Australian capital cities is different throughout the observed period. For example, the Moran's I values reach the lowest point over the observed period at about minus 0.1780 in Q1 of 2007, when the housing price in Sydney increased by about 3%. At the same time, the housing price in Canberra, which is the nearest city to Sydney, went up by 4%, while the rate of housing price increase in Darwin, which is located farthest from Sydney, was much higher. In Q3 of 2009, there appeared to be a weak negative spatial autocorrelation when the housing prices moved similarly in the cities that are close to each other. During the same period of time, the housing prices showed a relatively higher increase in Darwin and Perth, which are located in west and north Australia, while minimal increases or even a decrease emerged in all the east and south Australian cities.

The Z-scores of the Moran's I values confirm the significance of the different spatial autocorrelations at each time point over the observed period. Of the 70 time points, there are 44 time points at which the spatial autocorrelations are significant. It can be observed that the spatial autocorrelations are not significant in most of the observed sub-periods from 1998 to 2000. This insignificant spatial autocorrelation of the housing prices is caused by the flat movement of the housing prices in the Australian capital cities. This indicates that regional geographical effects did not influence housing prices very much from 1998 to 2000. The spatial autocorrelations are observed to be significant in the remaining sub-period, thus suggesting that geographical factors should be taken into account for robustness in the movement of housing prices in Australian capital cities. Since significant and negative spatial autocorrelations of housing price varied over the observed period, a time-varying spatial model is appropriate for investigating housing price movements.

4. House Price Convergence in Australian Capital Cities

4.1 Cointegration Tests of House Prices

As discussed above, the house prices in the Australian capital cities are integrated at the first difference. Subsequently, a co-integration test is carried out to identify whether there are long-run equilibrium relationships among the house prices. This research adopts the Johansen cointegration trace test to investigate the long-run equilibrium relationships. The null hypotheses for the trace test is the number of cointegration vectors (r) is r ≤ m, where m is less than eight in this study. The testing results are presented in Table 4.

Figure 1 Spatial autocorrelation tests

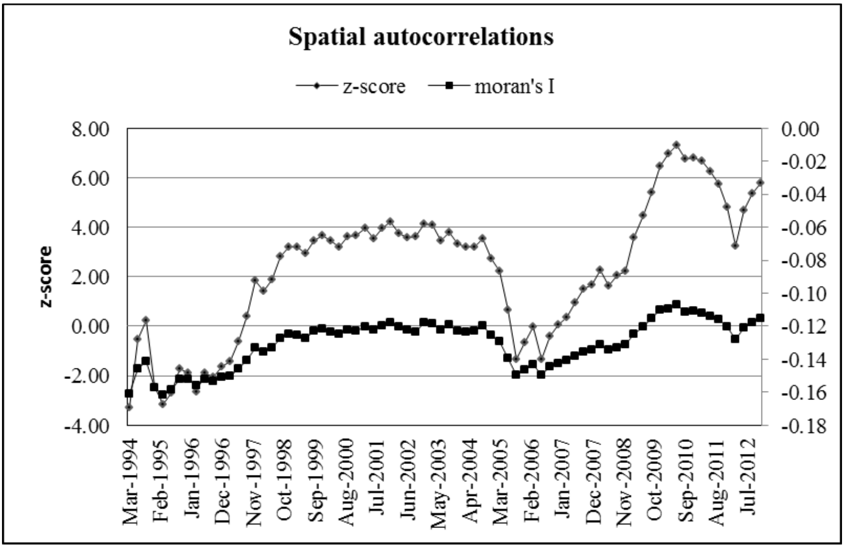


Table 4 Cointegration Test Results for House Price Indices

Hypothesised no. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	P-value
None *	0.6880	270.3574	159.5297	0.0000
At most 1 *	0.6514	192.3070	125.6154	0.0000
At most 2 *	0.4580	121.6867	95.7536	0.0003
At most 3 *	0.3861	80.6491	69.8188	0.0053
At most 4 *	0.2953	47.9509	47.8561	0.0490
At most 5	0.2181	24.4990	29.7970	0.1801
At most 6	0.1055	8.0146	15.4947	0.4639
At most 7	0.0080	0.5431	3.8414	0.4611

Note: * denotes rejection of the hypothesis at the 0.05 level.

Table 4 shows that long-run cointegration relationships exist among house prices in the Australian capital cities. According to the p-value of the statistics, the null hypothesis is rejected when the number of cointegration vectors is greater than four. Therefore, there are five cointegration vectors. The cointegration test indicates that the house prices in the Australian capital cities, as a segmented but related aggregation, should move towards a steady state in the long-run. The corresponding segmentations and relations among the house prices may be caused by spatial heterogeneity and spatial autocorrelations respectively. The following sections will provide details on an investigation as to whether house prices in the individual capital cities converge to a certain steady state, after taking into account the spatial effects.

4.2 Convergence of House Prices

The information described above has been utilised to build a spatio-temporal model for the convergence of house prices in Australia. Table 5 presents the estimated coefficients of the convergence of the house price modeling. An R-squared value of 0.2193 for the model is also reported in the last row of the table. The R-squared value indicates that over 20% of the variances can be explained by the model. In other words, the model accommodates the data well.

Table 5 Spatio-Temporal Convergence

Cities	α_i	β_i	ρ_i	γ_i	Club Convergence
Adelaide	-0.0245	0.0052 (0.4362)	0.0133 (0.8984)	-0.8786** (0.0000)	No
Brisbane	0.0044	-0.0014 (0.8204)	0.3911** (0.0000)	-0.7632** (0.0001)	No
Canberra	0.0178	-0.0042 (0.5650)	0.0736 (0.5101)	0.9046** (0.0000)	Uncertain
Darwin	-0.0230	0.0068 (0.4411)	0.2426** (0.0292)	-0.0276 (0.8630)	No
Hobart	-0.0176	0.0038 (0.6328)	0.0469 (0.6769)	0.6005** (0.0000)	No
Melbourne	0.0570	-0.0087 (0.2967)	-0.0632 (0.5765)	0.5093** (0.0207)	Uncertain
Perth	0.0165	-0.0021 (0.7072)	0.0845** (0.0000)	0.0042 (0.9784)	Uncertain
Sydney	0.1693	-0.0332** (0.0000)	0.0613 (0.5289)	0.8731** (0.0000)	Yes
R-squared	0.2193				

Note: The numbers in brackets are the p-values of the t-statistics with the null hypothesis where the coefficient is equal to 0. ** and * denote the t-statistics that are significant at the 5% and 10% levels respectively.

It is shown that the estimates of α_i and β_i are different across the Australian capital cities. This suggests that the house prices in the Australian capital cities should have distinct steady states and different paths of convergence. The estimates of α_i range from the lowest at -0.0245 in Adelaide to the highest of 0.1693 in Sydney. It is also reported that Melbourne has the second highest steady state, while Darwin, the second lowest steady state. This implies that house prices in Sydney and Melbourne will reach higher prices than the other cities if the house price system in Australia can reach equilibrium. On the other hand, the house prices in Adelaide and Darwin should be the lowest.

The estimates of β_i , which vary from -0.0332 to 0.0068, indicate the differences of the growth paths for these house prices. The estimate is significant and negative for Sydney, which suggests that the house price level in Sydney can reach the steady state. The estimates for Brisbane, Canberra, Melbourne and Perth are negative but insignificant. This implies that the house prices in these cities will potentially converge to their own equilibrium, although this is not certain. The half-lives calculated in accordance with the estimates of β_i show that a time period of around 5 years is needed for Sydney to increase at half of its current growth rate. Meanwhile, it will take nearly 20 years for Melbourne, 41 years for Canberra, 82 years for Perth and over 125 years for Brisbane to reduce the rate of their growth by 50 percent. Moreover, insignificant and positive estimates of β_i are found in Adelaide, Darwin and Hobart. The house prices in these three cities are predicted to diverge.

The estimated coefficients of the temporal and the spatial lags also vary across the Australian capital cities. The temporal coefficients are positive and significant for Brisbane, Darwin and Perth. This suggests that the growth of house price is strongly influenced by their previous movements. The estimates of the temporal lags for Adelaide, Canberra, Hobart and Sydney are not significant even at the 10% level. This suggests that the movement of the house prices in these cities is unlikely to be influenced by their previous behaviours. A negative and insignificant estimate of the temporal lag is reported in Melbourne. Unlike the other cities, previous movements of house price levels in Melbourne negatively contribute to its current activity. This means that a former increase in house price level would deter future growth in Melbourne.

The coefficients of the spatial lags show the relationships between house price movement and the previous behaviour of the neighbouring house prices. Positive estimates are reported for all the cities. This suggests that a house price growth in each of the eight cities should have a positive correlation with the house price movement in the neighbouring cities. The estimates of the spatial lags are insignificant in Darwin and Perth. This shows that the movement of house prices in these two cities tends to be independent of their neighbouring cities due to their remote geographical location. Positive and significant spatial coefficients are found for Adelaide, Brisbane, Canberra, Hobart, Melbourne and Sydney. Canberra has the largest coefficient, possibly caused by its smaller scale of development in the housing market. Adelaide has the second largest coefficient, mainly due to its central geographical location.

In summary, the results from the convergence modeling suggest that the house prices of Sydney should converge to a steady state. Weaker convergence may exist in the house prices in Brisbane, Canberra, Melbourne and Perth. The house prices of Adelaide, Darwin and Hobart will diverge. In order to simulate the movement of house prices, general impulse response functions based on the developed model will be used in this study. The results and illustrations are subsequently provided.

4.3 Prediction of House Prices

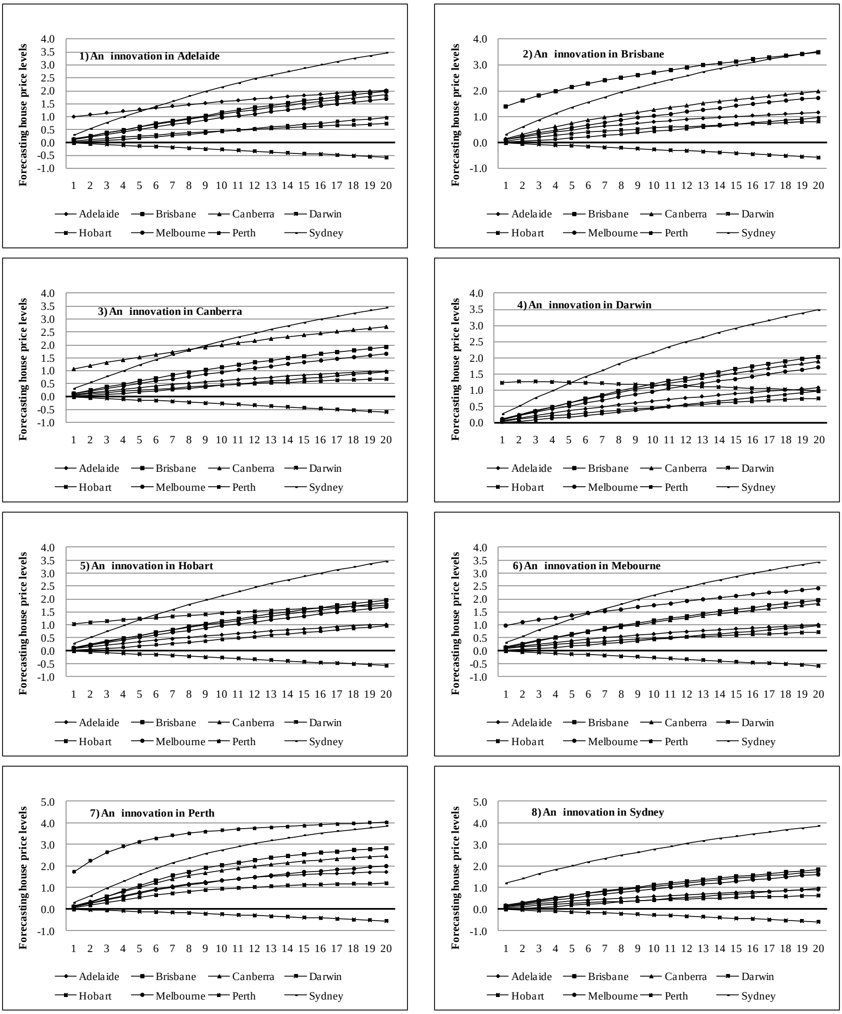
By using impulse response functions, the house prices of the eight capital cities in Australia will be predicted. It is assumed that if one unit of increase emerges in one of these cities, the initial prices are zero for the other cities. Based on the estimated results of the model that are presented in Table 5, the house prices in the eight capital cities can be predicted for each period. For example, if an initial shock occurs in Adelaide in Period 0, the changes in its house prices in Period t can be calculated as follows:

$$\Delta p_{Ade,t} = -0.0245 + 0.0052 * p_{Ade,t-1} + 0.0133 * \Delta p_{Ade,t-1} \\ -0.8766 * p^{w}_{Ade,t-1}$$

Similarly, the changes in the house prices in the other cities can be calculated for the predicted periods. Subsequently, the predictions of the house prices in the Australian capital cities are made, when initial shocks occur in the other seven cities.

By plotting all of the predicted prices at each time point of the entire period of prediction, both the spatial and the temporal tendencies are examined. Figure 2 presents the predicted house prices of the Australian capital cities for 20 quarters (5 years), separately from each other where a positive price innovation occurs. This shows that the house prices of the capital cities are significantly influenced by the shocks from the local markets in the early periods. The house prices in Adelaide, Hobart and Darwin do not appear to move in the same direction as the other cities over the periods, unless an initial shock of the house prices occurs in the local markets. Although long-run equilibrium relationships do not exist in the housing markets of these three cities, the housing markets in Adelaide, Darwin and Hobart filter the short-run dynamics in the housing markets of the Australian capital cities. The house prices of Hobart are always the lowest, unless the initial shock is in its local market. The house prices of Sydney are higher than the other cities over the 5 years, regardless of the origins of the price innovation. Therefore, the housing market in Sydney is the most stable.

Figure 2 Predictions of House Prices in Australia's Capital Cities



Significant differences are observed from the responses of Perth and Brisbane to the shocks in the local and neighbouring markets. The house prices of Perth start at around 0.017 and end at about 0.965, when the initial innovation of prices occurs in the neighbouring markets. The house price in Perth increases by 70% in the first period and will experience a growth of 4.04 in the 5 years, if one unit of increase takes place. A similar situation can be observed in Brisbane. A 10% initial increase and a final increase of 90% in the house price of Brisbane are caused by one unit of increase in the neighbouring cities. A one unit of increase in house price in the local market can lead to a growth of 39% in Brisbane in the first period, and a 250% increase in the house prices of

Brisbane can be eventually attained. The findings therefore suggest that investments in the housing markets in Perth and Brisbane can lead to correspondingly higher returns.

5. Conclusions

In this research, a spatio-temporal model is applied to investigate the characteristics of house price convergence in the capital cities of Australia. Temporal and spatio-temporal lags have been implemented to improve the convergence modelling so as to explore the long-run equilibriums in Australian house price. Impulse response functions are used to simulate the future performance of the house prices by assuming that a one unit of increase in shock occurs in one of the cities. The results indicate that the house prices in Sydney converge to a steady state, while weaker convergence is found for Brisbane, Canberra, Melbourne and Perth. The house prices of Adelaide, Darwin and Hobart appear to diverge. The prediction of the house prices show that the prices in Sydney would be the highest regardless of the location of the initial shock. The house prices of Darwin tend to depreciate when the house prices increase in the neighbouring markets. The predictions of the house prices in Perth and Brisbane show a significant increase when the initial shocks occur in the local markets rather than the neighbouring markets.

It can be implied that the housing market in Sydney is efficient. The house price dynamics are mainly caused by the neighbouring markets and its previous movements. Therefore, accurate predictions of house prices in Sydney can be carried out, as long as temporal and spatial effects are taken into account. The housing markets in the cities where weaker convergence appears are less efficient, thus suggesting that higher risks are involved with these housing markets. The housing markets in Adelaide, Darwin and Hobart seem to be correspondingly more volatile, since no long-run equilibrium can be found in the house prices. Therefore, Australian national and local governments should launch appropriate housing policies, in accordance with the characteristics that pertain to the individual housing markets. Investors can also benefit from these findings to build different portfolios that include various investment strategies.

References

ABS. (2013a). Building Approvals. Cat no. 8731.0. Australian Bureau of Statistics, Canberra.

ABS. (2013b). House Price Indexes: Eight Capital Cities. Cat no. 6416.0. Australian Bureau of Statistics, Canberra.

Anselin, L. (1988). *Spatial Econometrics: Methods and Models*. Kluwer Academic Publishers incorporates, Dordrecht.

Beenstock, M. and Felsenstein, D. (2007). Spatial Vector Autoregressions. *Spatial Economic Analysis*. 2, 2, 167 - 96.

Cook, S. (2003). The Convergence of Regional House Prices in the UK. *Urban Studies*. 40, 11, 2285-94.

Dicky, DA & Fuller, WA (1979) Distribution of the Estimators for Autoregressive Time Series with A Unit Root. *Journal of the American Statistical Association*. 74, 336, 427-31.

Drake, L. (1995). Testing for Convergence between UK Regional House Prices. *Regional Studies*. 29, 4, 357-66.

Fingleton, B. (2008). A Generalized Method of Moments Estimator for a Spatial Panel Model with An Endogenous Spatial Lag and Spatial Moving Average Errors. *Spatial Economic Analysis*. 3, 1, 27 - 44.

Greene, W. H. (2002). *Econometric Analysis*. Pearson Education, Inc., New Jersey.

Holmes, M. J. (2007). How Convergent are Regional House Prices in the United Kingdom? Some New Evidence from Panel Data Unit Root Testing. *Journal of Economic and Social Research*. 9, 1, 1 - 17.

Holmes, M. J. and Grimes, A. (2008). Is There Long-Run Convergence Among Regional House Prices in the UK? *Urban Studies*. 45, 8, 1531 -44.

Holly, S, Pesaran, M. H. and Yamagata, T. (2010). A Spatio-Temporal Model of House Prices in the USA. *Journal of Econometrics*. 158, 1, 160-73.

Holly, S, Pesaran, M. H. and Yamagata, T. (2011). The Spatial and Temporal Diffusion of House Prices in the UK. *Journal of Urban Economics.* 69, 1, 2-23.

Liu, C., Ma, L., Luo, Z. and Picken, D. (2009). An Interdependence Analysis of Australian House Prices Using Variance Decomposition. *International journal of Housing Markets and Analysis*. 2, 3, 218 - 32.

Ma, L. and Liu, C. (2010). The Decomposition of Housing Market Variations: A Panel Data Approach. *International Journal of Housing Markets and Analysis*, 3, 1, 6 - 16.

MacDonald, R. and Taylor, M. P. (1993). Regional House Prices in Britian: Long-run Relationships and Short-run Dynamics. *Scottish Journal of Political Economy,* 40, 1, 43-55.

Meen, G. (1996). Spatial Aggregation, Spatial Dependence and Predictability in the UK Housing Market. *Housing Studies*. 11, 3, 345-72.

Moran, P. (1950). Notes on Continuous Stochastic Phenomena. *Biometrika*. 37, 1-2, 17-23.

Pesaran, M. H. and Shin, Y. (1998). Generalized Impulse Response Analysis in Linear Multivariate mOdels. *Eonomics Letters*. 58, 1, 17-29.