A SPATIAL DECOMPOSITION APPROACH FOR INVESTIGATING HOUSE PRICE CONVERGENCES

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ABSTRACT: Convergence of house prices indicates how prices are reaching an aggregate equilibrium in a long-run perspective. Identifying the convergence is important for cross-region housing development and investment. Few studies have identified house price convergences at different levels, with spatial effects on house prices predominantly ignored. The research presented here developed a spatial panel regression approach to investigate the convergences of house prices in Australian capital cities. Three hypotheses were tested to identify the level of house price convergence. The results demonstrate that a steady state in a system of regional house prices and spatial effects contribute to the convergence continuing.

1. INTRODUCTION

For decades, researchers have been using a series of housing fundamentals to explain and forecast house price behaviours. Various structures and the unique locations of houses determine house price segmentation across regions. Transportation of equity and migrants results in house prices being interconnected between regions. The notions of house price segmentation and diffusion pattern subsequently lead to concerns about convergence of house prices across regions in a country. If the convergence exists, regional house prices in a nation will move towards a steady state, which can be

represented by a vector. Identification of house price convergence is important for making decisions on balanced housing development and investment across regions in a country. Regional house price convergence is the existence of constancy in the gaps between a regional house price and a benchmark, such as a national price or a price in a dominant region (MacDonald and Taylor, 1993). The majority of research investigates house price convergences under an assumption with strong restrictions, which leads to a failure to provide convincing evidence to support the convergences. In addition, it has been widely recognised that spatial correlation is an important factor affecting regional house prices (Anselin and Lozano-Gracia, 2008; Basu and Thomas, 1998; Can and Megbolugbe, 1997; Goodman and Thibodeau, 2007). Therefore, ignorance of spatial effects on house price can be recognised as another weakness of the previous investigations of house price convergences.

In productivity convergence research, there are three main convergence hypotheses, namely unconditional, conditional and club convergences. Under each of these specific convergence hypotheses, different restrictions are placed on the steady state and the converging path. Barro and Sala-i-Martin (1992) were the first to develop the model which investigates unconditional convergence. The key element of unconditional convergence is to look at whether the levels of regional economy will converge to a constant vector for all the regions over a specific time period. Conditional convergence requires that the economies are assumed to move towards their own steady states. Steady states are distinct across regions because of the different regional structures, such as income, population, and market scales. As stated by Galor (1996), club convergence means that regions which are similar in their structure converge to the same steady-state equilibrium if their initial levels are similar as well. In other words, under the club convergence concept, the transitory movements of regions may permanently affect performances. Moreover, spatial correlations have been widely applied in the studies of productivity convergence (Arbia *et al.*, 2008; Arbia and Paelinck, 2003; LeSage and Fischer, 2008; Xu and Harriss, 2010).

This research will contribute to the literature on regional house price convergence by investigating three hypotheses of convergences. Spatial effects on house price convergences will also be involved in the convergence investigations in this research. Throughout this

research, spatial regression models are constructed to investigate the convergence of house prices against the three hypotheses. House price indexes in the eight capital cities of Australia from 1989 to 2012 are used to interpret the models. The rest of this paper is organised as follows: the second section proposes three hypotheses after reviewing previous literature on house price convergence. The third section illustrates the theoretical framework of spatial decomposition of house prices. The fourth section develops the spatial panel regression models to investigate the house price hypotheses. The fifth section describes the information of housing in the eight Australian capital cities. The sixth section presents the empirical results of the convergence hypotheses investigation. The final section concludes. The empirical results not only depict the convergence process of Australian regional house prices, but also disclose the effects of spatial correlations during the convergence process.

2. HYPOTHESES

In the work of MacDonald and Taylor (1993), long-run equilibrium relationships or the convergence between regional house prices were also investigated. However, they failed to prove that regional house prices in the U.K. converged to a steady state. Drake (1995) conducted a formal test for the convergence of different ratios of regional house prices in the UK. Once again, no strong evidence was generated to support the convergence of house price different ratios. A time-series testing method widely used to investigate convergence of regional house price different ratios can be expressed as follows:

$$d_{it} = \alpha + \beta d_{i,-1} + \varepsilon_{it} \qquad (1)$$

Where $d_{it} = HP_{it} - HP_{0t}$ is the difference of the house price in a region i and the benchmark house prices, such as national house prices or the house prices in a central region. The symbols α and β are estimated coefficients. Specifically, coefficient α stands for a steady state, while coefficient β indicates a converging speed, and ε is a residual of the model. The house price ratio in region i, against a benchmark price, converges to a steady state in a continuous period t, only if d_{it} is stationary, which requires that $\beta < 1$. This so called

"stationary test" or "unit root test" method has been widely used to investigate the convergence of house price ratios. Cook and Thomas (2003) argued that the limitation of Eq. (1) led to the failure of uncovering the existence of convergence. Alternatively, they proposed an asymmetric unit root test to capture the convergence of house price different ratios. The pair-wise convergences of regional house price ratios in the U.K. were investigated by using the asymmetric method. The detection of convergence was not strongly supported by the research evidence. Within those time-series studies, house price convergence is assumed to be in correlation with regional structures or initial price indexes. Nevertheless, effects of spatial heterogeneity and spatial correlations are ignored by those studies. Therefore, the convergences can hardly be detected using time-series methods.

Holmes (2007) proposed an innovative approach to investigate house price convergence by improving unit root tests with a panel regression framework. This panel unit root model assumed the convergence should be correlated with regional structures, which can be captured by the spatial dependence in the steady state. Moreover, contemporary spatial correlations are taken into account by using a seemingly unrelated regression. Holmes applied the panel unit root to U.K. regional house prices. The findings showed that the panel regression model was more powerful than the purely time-series model. Convergences of house price ratios were detected in most regions of the U.K. The panel unit root tests were subsequently improved by implementing the first principal component (Holmes and Grimes, 2008). However, the house price convergence detected by this panel regression approach is assumed not to be correlated with initial regional prices. Lagged spatial effects have not been undertaken in this panel regression approach either.

In order to provide a comprehensive understanding of house price convergences, this research investigates the convergences against three hypotheses respectively. The three hypotheses are expressed as follows: Club convergence (H1): House price convergence is associated with regional structures and initial price. In regions with similar structures, house prices with similar initial prices will reach a steady state.

Conditional convergence (H2): House price convergence is associated with regional structures. In regions with similar structures,

house prices have greater growth rates in regions with low initial price than regions with high initial price.

Unconditional convergence (H3): House price convergence is not associated with regional structures or initial price. House prices grow more rapidly in regions with low initial price than regions with high price.

In order to capture spatial effects on house prices, this research will test the three hypotheses under a spatial decomposition of house prices.

3. SPATIAL DECOMPOSITION OF HOUSE PRICES

In order to understand the behaviours of house prices, a number of studies argued that house prices can be decomposed into a series of fundamental factors. Houses are widely regarded as assets, and thereby rents generated from houses are viewed as returns on the assets. Poterba *et al.* (1991) argued that the housing market consisted of the market for existing houses and the market of new construction, shocks in either of which would influence the house prices. Abelson *et al.* (2005) proposed that changes in house prices should be decomposed into a series of long-run and short-run fundamental factors representing the differences between the supply and demand of housing. Fundamental house price theory looks into housing behaviours at an aggregate level and ignores spatial effects on house prices, leading to inaccurate results. The effects of spatial correlations on house prices were mentioned in recent research on house prices from a national perspective. Beenstock and Felsenstein (2007) proposed a spatial vector autoregression model to explore the relationships between house price movements and fundamental factors across regions. Their work shed light on the theoretical framework of conducting a spatial and temporal analysis of regional house prices. Holly *et al.* (2010) developed a spatio-temporal model to analyse house prices in the U.S.A. The determinants of house prices in 49 American states were studied. They argued that real incomes could lead to the change of house prices. A significant spatial dimension was also found among the state level housing data. Similar research on state-level house prices in the U.S.A was conducted by Kuethe and Pede (2011).

In order to capture spatial effects on house prices, Bourassa and Hendershott (1995) extended the fundamental decomposition of house prices, while they investigated the house prices in Australian capital cities. They argued that house prices should be illustrated by the fundamental prices and error terms, which were the differences between the estimated prices and the actual prices. Ma and Liu (2010) proposed a three-dimensional decomposition of house prices under a panel regression framework. They demonstrated that a regional house price change should be influenced by regional specific factors, home-market factors and neighbourhood-market factors. Costello *et al.* (2011) also argued that house prices should be decomposed of fundamental and non-fundamental components. The deviations of fundamental house prices and actual house prices were investigated and evidenced by Costello's research in the national and regional markets in Australia.

Fundamental models argue that house prices are assessed against evolution of the user cost of home ownership. This cost takes account of the returns associated with the cost of housing generated from marginal tax rates, mortgage rates, property tax rates, depreciation rates, risk premium rates, maintenance rates, and expected capital appreciation rates. Poterba *et al.* (1991) argue that equilibrium in the market for existing owner-occupied houses can be achieved if the homeowners earn the same return on housing investment as on other assets, which can be expressed as follows:

$$\frac{HP_t^{fundamental}}{HP_0} = (1 + \tau + f + \delta - r)^t \tag{2}$$

HP_0 and $HP_t{}^{fundamental}$ denote the initial purchase price and the fundamental price of a house ina future period t. Symbol τ denotes after-tax nominal mortgage rates, f is the property tax rates, δ stands for the depreciation, maintenance and risk premium rates, and r is the average rent-price ratio per period. However, Ma and Liu (2010) argue that regional house markets should be composed of three components - regional characteristics, own market characteristics and neighbouring market characteristics. Costello *et al.* (2011) also argued that house prices could not be completely reflected by fundamental factors. Instead, some non-fundamental factors not only

influence regional house prices but also affect the interconnections across regions. This research assumes that spatial correlations between house prices should be regarded as one non-fundamental factor. As such house prices will be expressed as follows:

$$HP = (HP_{fundamental})(HP_{spatial})\gamma \qquad (3)$$

Where $HP^{spatial}$ stands for the spatial correlations between regional house prices, and β and γ are estimated elasticity. Substituting $HP^{fundamental}$ with *Eq.* (1), *Eq.* (2) can be rewritten as follows:

$$HP_t = [HP_0(1 + \tau + f + \delta - r)^t]^\rho (HP^{spatial})^\gamma \qquad (4)$$

Taking logs in both sides of *Eq.* (3), and using lower letters to indicate the logarithm values of house prices. By denoting $\alpha = (1 + \tau + f + \delta - r)$ and $\beta = \rho - 1$, *Eq.* (4) can be converted to:

$$p_t - p_0 = \alpha + t\beta p_0 + \gamma p^{spatial} \qquad (5)$$

Seen from *Eq.* (5), house prices will converge if $\beta < 0$. In other words, house prices are convergent to a steady state, when their growth negatively correlates with the initial prices.

Three different assumptions for convergence were widely investigated by studies on economic growth, which include unconditional convergence, conditional convergence and club convergence. Based on the framework of house price convergence, this research investigates each of the three converging assumptions of regional house prices.

4. THEORETICAL MODELS FOR THE THREE CONVERGENCE HYPOTHESES

In this research, the three hypotheses of house price convergences are investigated by spatial panel regression models and spatial cross-sectional regression models. The club convergence hypothesis assumes that regions which are similar in their structure should converge to the same steadystate equilibrium if their initial levels are

similar as well. In other words, under the club convergence assumption, the transitory movements of regions may affect performances permanently. Therefore, regions with different initial prices and structures may have distinct pathways to arrive at their own equilibrium states. This research applies a panel regression technique to investigate club convergence in a continuous time framework. The panel club convergence model can be expressed as follows:

$$p_{it} - p_{i,t-T} = \alpha_i + \beta_i p_{i,t-T} + \gamma p_{i,t-T}^s + \varepsilon_{it} \qquad (6)$$

p_{it} denotes the logarithm values of house prices in region i at the initial time and the final time points of the sub-period respectively. ε_{it} is the error term with 0 mean and constant various. p_{it}^s is the spatial lag, defined by $p_{it}^s = \sum_{j \neq i}^N w_j p_{jt}$, where N equals the number of regions. p_{it}^s can be viewed as a weighted average house price in the neighbouring markets for region i, distributed according to the spatial weight w_j. Symbol α is the estimated constant term denoting the steady level towards which the house prices will converge, while γ illustrates how deeply house price may be influenced by the neighbouring markets. The estimated coefficient β indicates how fast the house prices will converge to the steady state. The smaller the value of β, the faster the house prices will move towards steady states.

The above model allows for the distinctions of steady equilibrium states across cities. Moreover, the converging paths, indicated by the estimations β_i, are able to vary from city to city. A seemingly unrelated regression method satisfies the temporal correlations between sub-periods. The system expression of *Eq.* (6) is presented as follows:

$$\Delta P_t = A + B P_{t-4} + U_t \qquad (7)$$

Where $P_t = (P_{1t}, P_{2t}, \cdots, P_{Nt})'$, $A = (\alpha_1, \alpha_2, \cdots, \alpha_N)'$,
$U_t = (u_{1t}, u_{2t}, \cdots, u_{Nt})'$,

$$B = \begin{pmatrix} \beta_1 & \cdots & 0 \\ 0 & \ddots & 0 \\ 0 & \cdots & \beta_N \end{pmatrix} + \begin{pmatrix} \gamma_1 W_1' \\ \vdots \\ \gamma_N W_N' \end{pmatrix}, \text{ and}$$

$$W_i = (w_{i1}, w_{i2}, \cdots, w_{ii-1}, \ 0, \ w_{ii+1} \cdots, w_{iN})',$$

The conditions for convergence to a stable equilibrium are derived from the negative eigenvalues of the estimated matrix B. This means that whether there is $\lambda < 0$, satisfying $|B - \lambda I| = 0$, will indicate the convergence property of house prices over continuous time.

If the proceeding house price convergence is unrelated to the initial price across regions, the house prices should fit a conditional convergence hypothesis. Under this hypothesis, house prices will move towards their own steady states if they have similar socio-economic structures, such as incomes, population, and market scales. Under the conditional convergence hypothesis house prices are converging at the same speed over a certain time period, therefore the growth of a house price is higher if its original price further separates from the steady state. A spatial cross-sectional model indicating the conditional convergence is expressed as

$$p_{iT} - p_{i0} = \alpha_i + \beta p_{i0} + \gamma p_{i0}^s + \varepsilon \tag{8}$$

Seen from *Eq.* (8), the estimated α_i are used to indicate the equilibrium levels and allowed to vary across cities over the observing period 0 to period T. The estimate β indicates the converging speed, which is assumed to be the same for all the regions.

Under the unconditional convergence hypothesis, it is assumed that, from period 0 to period T, house prices across regions should move towards a steady state at the same speed, regardless of regional structure and initial levels. This hypothesis can be tested by a spatial cross-sectional model which is expressed as follows:

$$p_{iT} - p_{i0} = \alpha + \beta p_{i0} + \gamma p_{i0}^s + \varepsilon \tag{9}$$

where the estimated α indicates the equilibrium level, and β is assumed to be the same for all the regions, denoting the convergence speed.

5. DATA DESCRIPTIONS AND PRE-PROCESSING

Australian House Price Indices

This research uses the House Price Indices (HPI) to represent the house price changes in the Australian capital cities. The HPI of the eight capital cities of Australia were collected from the publications of the Australian Bureau of Statistics (ABS 2013). The period chosen was from the December quarter, 1989 to the March quarter, 2012. The indices are constructed by using a stratification approach (ABS 2005). Houses in the cities are stratified by suburb or postcode, types, number of bedrooms, overall sizes, and neighbourhood characteristics such as proximity to shops, schools, and hospitals, and levels of crime etc. The objective of this approach is to minimise the physical heterogeneity of dwellings within each stratum and to confirm that location is one of the key determinants of the prices of houses. In each period the median price movement is calculated for each stratum and used to construct a stratum level price index. The aggregate index is calculated by weighting together the individual stratum index, where the weights represent the relative significance of the stock of dwellings in each stratum.

The indices were initially based on the quarterly house prices for established and newly erected dwellings and each capital city's house price indices 1989-90=100. However, the reference base of the published HPI changed for the 2003-04 financial year after the September quarter, 2005 (ABS, 2005). In order to maintain consistency, the old reference base (1989-90) has been used in this research. The method used to convert the re-referenced data to the previous base is described as $HPI_{89-90} = r \times HPI_{03-04}$, where HPI_{89-90} denotes the house price index on the base 1989-90 = 100, HPI_{03-04}, denotes the house price index on the base 2003-04 =100, and r is the converting factor, which is the index number for year 2003-04 on the base 1989-90 divided by 100. Figure 1 shows the house prices in the eight capital cities.
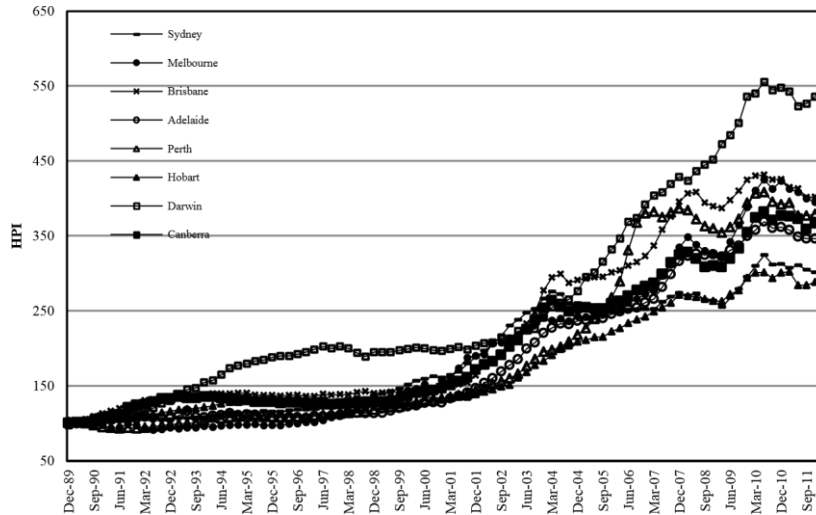
Figure 1. House prices indices in eight Australia's capital cities.
Source: ABS (2013).

The biggest change in house prices was in Darwin (350.3%) during the investigated period, the city with the smallest population of the eight studied. The Darwin housing market showed a very different behaviour to the other seven markets. Darwin started its increase from the very beginning of the observation period, up until the December quarter, 2008. It had an average change rate of 3.62% per quarter followed by a steady increase until the September quarter, 2000. The latest sharp increase in Darwin started in the December quarter, 2001. The other seven cities showed a similar propensity during this period. They all have slow increase trends at first, and move up dramatically after 1996. The house market boom in Melbourne, Adelaide, Perth and Sydney occurred earlier than in the other markets. Instead of being led by Australia's biggest city Sydney, the house market boom originated in Melbourne, which is the second biggest city in Australia, in the December quarter of 1996. The booms in Sydney, Adelaide and Perth started in the March quarter, 1997, followed by Brisbane (June quarter, 2002), Canberra (June quarter, 2000) and Hobart (June quarter, 2000).

This research uses Augmented Dicky-Fuller unit root test (ADF) (Dicky and Fuller, 1979) to identify the stationarity of the house

prices. Table 1 shows the unit root test results of eight capital cities, using the ADF unit root test.

Table 1. Eight capital cities' house price index series unit root tests.

		ADF test at level			ADF test in first difference		
		P-value	Sig.	Lag	P-value	Sig.	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

Source: the Authors.

The null hypothesis of 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. They are shown in Table 1 respectively: no trend and intercept, intercept without trend and, intercept and trend. The results shows that eight capital cities' house price index data series are not stationary at the level form but stationary after the first difference at the 1% and 5% significance levels. That is, all the eight data series are integrated at the first difference level.

Spatial Dependence of House Prices

Anselin and Lozano-Gracia (2008) describes spatial econometrics as a subfield of econometrics that deals with the treatment of spatial interconnections and spatial structures in regression models for cross sectional and panel data. From the description above, it can be seen that there are three main notions in spatial econometrical analysis, namely spatial interconnections or spatial dependencies, spatial heterogeneities, and spatial locations of observations. Spatial dependence in a collection of observations refers to the phenomena that an observation in a location correlates with the observations in other locations. The core focus of spatial econometrics is to address the spatial dependence among the observations of interest. In spatial econometrical regression models, spatial dependence represents spatial effects and is expressed either in the form of spatially lagged dependents or in the form of error structures. The former has been used in this research. Spatial heterogeneity refers to the distinctions in relationships across regions. In the regression context, spatial heterogeneity can be carried out by varying parameters, and random coefficients (Anselin and Lozano-Gracia, 2008). This research has mainly used varying parameters to deal with the spatial heterogeneity.

Spatial weights are often applied to quantify the locations of observations. There are various types of spatial weight constructions in spatial econometrics. Two themes can be classified. One is the constructing of spatial weights based on the distance between observations. The other is to use the contiguity reflecting the position of one observation to the others in the space. In this research, spatial weights have been constructed based on distance. Regions that are relatively closer to each other reflect a greater degree of spatial dependence than those with relatively longer distance from each

other. Briefly, the degrees of spatial dependence should negatively correlate with the distance between regions.

Geographic locations of houses are one of the most important determinants of their prices, due to the immobility of houses. Housing markets appear as apparent geographic clusters. The literature has identified ripple effects in the U.K. housing markets, which show that a shock of house price in London will spread to the house prices in other cities along the distances from it (MacDonald and Taylor, 1993; Meen, 1996; Meen, 1999). The recent work of Holly *et al*. (2011) employed spatial dependences, which were constructed by the geographic distance between cities, to investigate the house price ripple effects in the UK. The results confirm that the geographic distance based spatial regression model is successful in capturing the spatial interconnections between regional house prices in the UK. Liu *et al*. (2008) investigated the house price interconnections between the Australian capital cities, arguing there are spatial clusters among the capital cities' house prices. Moreover, the HPI published by ABS were estimated by a stratification approach, which confirms that the location of houses is a key determinant of their prices. Therefore, this research uses the geographic distances between the Australian capital cities to specify the spatial weights.

Australia has 6 states and 2 territories. The capital cities Brisbane (Queensland), Canberra (Australian Capital Territory), Melbourne (Victoria) and Sydney (New South Wales) are located in the east of Australia. Adelaide (South Australia), Darwin (Northern Territory) and Perth (Western Australia) are located in the central south, central north and west respectively. Hobart is located on a southeast island (Tasmania). Table 2 describes the straight-line distances between the Australian capital cities. Sydney and Canberra are only 248 kilometres apart. The city farthest from Sydney is Perth, at 3 288 kilometres. Darwin is located at the northernmost point of Australia, over 2 600 kilometres from the other cities. Perth, the furthest west, is 2 130 kilometres away from its nearest neighbour, Adelaide. Melbourne has the shortest average distance, followed by Canberra, Adelaide and Sydney. Melbourne can be recognised as the centre of Australian capital cities in a geographic context.

Table 2. The geographic distances between Australian capital cities (Km).

	ADE	BRI	CAN	DAR	HOB	MEL	PER	SYD
ADE	-	-	-	-	-	-	-	-
BRI	1600	-	-	-	-	-	-	-
CAN	957	946	-	-	-	-	-	-
DAR	2615	2846	3133	-	-	-	-	-
HOB	1161	1788	856	3734	-	-	-	-
MEL	653	1374	464	3146	597	-	-	-
PER	2130	3604	3085	2651	3008	2719	-	-
SYD	1161	732	248	3146	1057	713	3288	-

Source: the Authors.

The impact of one regional housing market on another may disperse over the distance between them, known as spatial dependence. In order to capture the spatial heterogeneity and the spatial information, a spatial weight matrix is involved in the model. The spatial effects of one housing market on another could be negatively correlated with the distance between them. Products of house prices and inverses of the distances construct the spatial effects between house prices. Denoting d_{ij} as the logarithm of the distance between city i and city j. the spatial weight for these two cities is defined as the reverse values of the distance, denoted by $w_{ij} = \frac{1}{d_{ij}}$. Accordingly, the weight matrix is expressed as

$$W = \begin{pmatrix} 0 & w_{12} & \cdots & w_{1N} \\ w_{21} & 0 & \cdots & w_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ w_{N1} & w_{N2} & \cdots & 0 \end{pmatrix} \qquad (10)$$

It is found that the geographic weight matrix is symmetric. It shows that there is no direction between two cities. In other words, the spatial weight from city i to city j is the same as that from city j to city i. Moreover, the spatial matrix is time invariable, indicating that spatial weights will not change over time. The house price dependence, $P^s = WP$, represents a new variable equivalent to the

mean of house prices from the neighbouring markets, $p_i^s = \sum_{j \neq i}^{N} w_{ij} p_j$.

6. INVESTIGATIONS OF THE THREE HYPOTHESES

Club Convergence

As mentioned in the previous section, club convergence hypothesis assumes that steady states and converging patterns should correlate with the structures of the cities and the initial levels. By using *Eq.* (6), the converging characteristics of house prices in Australian capital cities can be captured by the estimated spatial panel regression model, the correlations coefficients of which are reported in Table 3.

Table 3. Estimations of the club convergence model.

Cities	α	β	γ
Adelaide	-0.1572	-0.3907	0.4354
Brisbane	-0.0197	-0.5269	0.5824
Canberra	0.1625	-0.3058	0.2783
Darwin	0.0222	-0.2593	0.3254
Hobart	0.6610	-0.5810	0.4643
Melbourne	-0.1873	-0.1147	0.1597
Perth	-0.6263	-0.4481	0.6534
Sydney	0.1719	-0.0113	-0.0118

Source: the Authors

Seen from an individual housing market perspective, the estimated values of α are positive in Canberra, Darwin, Hobart and Sydney, but negative in the other four cities. The estimated values of β vary across cities and are negative in all the cities. This indicates that convergence may emerge in each of the Australian capital cities. Positive estimated values of γ for Australian cities suggest that the spatial effects on individual house price movements are aligned with the previous behaviours of its neighbouring markets. Among the cities with negative steady states, the biggest spatial effects are found

in Perth, followed by Brisbane, Adelaide, and Melbourne. Correspondingly, the convergence speeds of the house prices are found from the highest to the lowest in the same order in these four cities. Among the cities with positive steady states, Hobart, which is influenced most by spatial effects, has the highest convergence speed, while the lowest speed appears in Sydney, which is influenced least by the spatial effects.

Although the estimated coefficients show a potential possibility of club convergence in a continuous time in each of the individual housing markets of Australia, whether or not the club convergence exists at an aggregate level is dependent on the eigenvalues of matrix B, which was defined in the previous section. The components of matrix B are given in Table 4.

Table 4. Identification of matrix B for the club convergence.

	Adelaide	Brisbane	Canberra	Darwin	Hobart	Melbourne	Perth	Sydney
Adelaide	-0.3907	0.0575	0.0285	0.0198	0.0426	0.0430	0.2102	0.0339
Brisbane	0.0775	-0.5269	0.0257	0.0199	0.0329	0.2205	0.0976	0.1083
Canberra	0.0319	0.0216	-0.3058	0.0680	0.0909	0.0193	0.0293	0.0174
Darwin	0.0366	0.0278	0.1125	-0.2593	0.0649	0.0254	0.0348	0.0234
Hobart	0.0759	0.0439	0.1444	0.0622	-0.5810	0.0382	0.0660	0.0336
Melbourne	0.0147	0.0561	0.0059	0.0047	0.0073	-0.1147	0.0172	0.0538
Perth	0.3028	0.1048	0.0375	0.0270	0.0531	0.0730	-0.4481	0.0553
Sydney	-0.0011	-0.0027	-0.0005	-0.0004	-0.0006	-0.0052	-0.0013	-0.0113

Source: the Authors.

If matrix B has nonzero eigenvalues, the hypothesis of club convergence can be supported. There is one eigenvalue of matrix B equal to 0.1417. This indicates that house prices in the Australian capital cities can move towards a systematic steady state over continuous time at an aggregate level, when considering the spatial effects from geographic factors.

Conditional Convergence

Since the club convergence model suggested that house prices in Australia should move towards the steady states individually, the conditional convergence model can investigate the proceeding when the initial price indexes are uncounted. *Eq.* (7) assumes that house prices in the cities should have different steady states, if the house

prices fulfil the convergence. The interval of each sub-period is still one year, the estimated values of α are slightly distinct from city to city, indicating that the house prices in Australian capital cities will converge to different steady states. For each sub-period, the estimated coefficients of β and γ for the whole of the observation period are reported in Figure 2.
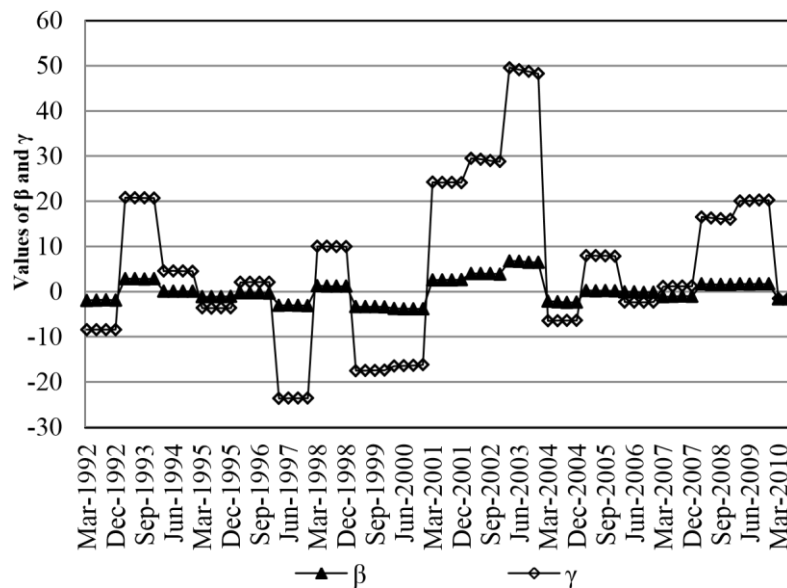

Figure 2. Estimations of the conditional convergence model. Source: the Authors.

The statistical results of *β* support the possibility of conditional convergence for house price indices. It is reported that *β* were negative in forty-three sub-periods, namely the sub-periods of 1992, 1995 to 1997, 1999 to 2000, 2004, 2006 to 2007, and 2010 to 2011. This suggests that under the conditional convergence hypothesis, house prices in the Australian capital cities converge to their own steady states over the observation period. Alternatively, the house prices do not move towards their individual steady states in the remaining sub-periods. It is interesting that the steady states appear to be extremely negative estimated values, when the unconditional convergence hypothesis cannot be fulfilled. In addition, the signs of the estimated values of γ, which suggest that the average influences of

the neighbourhood housing markets on house prices, are once again contrary to the signs of the steady states. These findings further support the inference generated above, which is that spatial effects will contribute to the convergence of house prices in Australia.

Unconditional Convergence

The unconditional convergence for house prices in Australia are captured by *Eq.* (9) at a national perspective. *Eq.* (9) assumes that the whole Australian housing markets should converge to the same steady state at an equal pace. The estimations of *Eq.* (9) were calculated based on Australian data and plotted in Figure 3. Out of the total 84 sub-periods, there are 43 sub-periods, where the house prices are proved to have unconditional convergence. It is reported that the converging rates are unstable across the observing period, ranging from -15.8523 to 4.0096. The house price in the Australian capital cities appears to increase in the majority of early sub-periods. After a slow-down period in 2001 and 2002, it reaches its peak in late 2006. The price indices have begun to decrease since 2007.
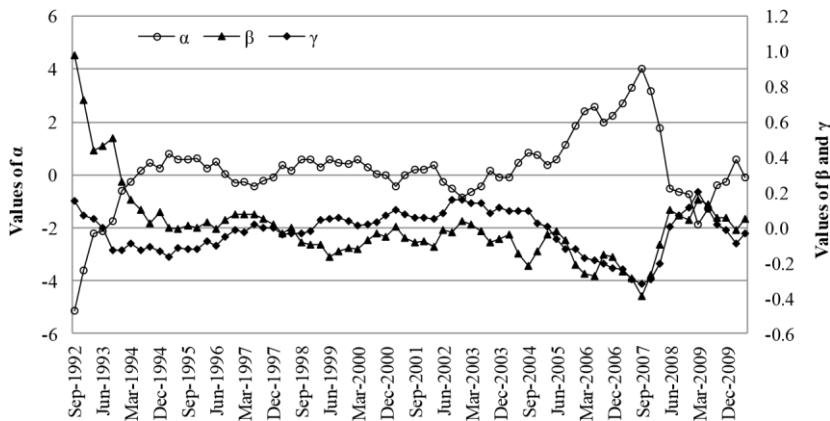

Figure 3. Estimations of the unconditional convergence model.
Source: the Authors

The evidence supporting the convergence of house prices to the same equilibrium level can be found in the sub-periods of 1994 to 1995 and 1997 to 2007. During the longest converging period, the

housing markets of Australia boomed. In particular, the cities with relatively lower price indices, such as Sydney, Melbourne and Brisbane, experienced relatively higher growth rates during that period. However, the house prices did not converge to the same steady state in the remaining sub-periods. During the early 1990s, house price indices moved at different speeds in different cities of Australia. This drives the house price indices in the Australian capital cities away from each other. During the post financial crisis periods, house price indices became increasingly moderate across Australia. In other words, the growth rates of house prices in the cities with relatively low price indices are no longer higher than the rates in the cities with higher price indices. Therefore, house price indices in the Australian capital cities fail to move towards the same steady state. For instance, the house price indices in Darwin and Perth were higher than the price indices in the other cities and they also experienced above-average annual increase rates from 2007. In contrast, house prices in Sydney, at a relatively lower level, experienced a continuous decrease during that period.

The estimated coefficients γ measure the spatial effects of the initial house price generated from the neighbouring markets. It can be seen that the signs of the spatial coefficients are contrary to the signs of the steady states in most of the sub-periods (fifty-seven sub-periods). This indicates that the effects from neighbourhood housing markets play a role as a filter which prevents the regional house price moving away from the periodic steady states. The spatial coefficients whose signs are the same as those of steady states are mainly distributed between 1998 and 2003. During these sub-periods, positive steady states and spatial effects contemporarily exist in the Australian housing market. One possible explanation is that the effects of the huge housing market boom across Australia overlapped the effects generated by the spatial factors.

To sum up, three converging types of house price convergence properties were investigated, through the cross-sectional and panel data regression methods. For a specific discrete time period, house prices in Australian capital cities converged to the same equilibrium with the same converging speed, especially when a huge nationwide house price boom emerged. Although the conditional convergence characteristics were supported in many sub-periods, the estimated values of the coefficients α, β and γ are not stable across the sub-

periods. This suggests that neither conditional nor unconditional convergence hypotheses can be applied to the Australian housing markets for a continuous time period. There is insufficient evidence to support the existence of convergence for the entire observation period. Another restriction of the above two convergence hypotheses is that the house prices in the Australian capital cities are assumed to converge at the same speed, regardless of the initial price indices in the cities. Therefore, this research uses a spatial panel regression model to investigate the club convergence hypothesis. When the steady states were allowed to vary according to the regional characteristics, convergence was found for all the sub-periods, where the house prices in cities were allowed for different paths of convergence. A systematic steady state was also found at an aggregate level.

7. CONCLUSIONS

This research introduced a spatial decomposition approach to investigate three convergence hypotheses against house prices in Australia, namely club convergence, conditional convergence and unconditional convergence. In particular, the club convergence model was estimated through the spatial panel regression model over a continuous time period. The results showed that club convergence was demonstrated in the individual housing markets in Australian capital cities, and also at the national level. This indicates that house prices in Australian capital cities converge to different steady states at different speeds.

Within the discrete time, unconditional and conditional convergence models were established based on the cross-sectional regression method over one year. The results showed that the unconditional and conditional hypotheses were discovered in the majority of the observation sub-periods. In other words, house prices in the Australian capital cities cannot move towards the same level or through the same path, due to the distinctions of the cities.

Moreover, spatial distance between each pair of cities in Australia was used to construct the spatial weights, while estimating the spatial econometrical models. Spatial heterogeneity of house prices exists across Australian capital cities. Spatial spillover effects were also estimated in the framework of the spatial convergence models. The

spatial effects appeared to be significant, which indicates that the average growth rate of house prices in a given city is affected by the average growth rate in its neighbouring cities. Evidence also showed that spatial effects contributed to driving the house prices towards a state of equilibrium across Australia.

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