科技部補助專題研究計畫成果報告
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漣漪效應與區域房價動態相關之影響因素

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中 文 摘 要 ： 本計畫研究區域間房價的動態互動關係以及漣漪效應的可能成因，選擇英國為分析之樣本國家。運用Copula模型所計算的動態相關係數分析英國倫敦地區與其他地區在過去四十年間的關係。發現地區間的關係多發生在經濟情況較差的階段，譬如1980年代初期、1990年代初期與2008金融海嘯時期，在樣本期間內，倫敦與各地區房價動態相關係數並沒有結構性轉變，但卻有慢慢降低的趨勢。本研究也運用因果關係測試(Granger causality test)，分析各區房價動態關係是否受到人口、所得、失業率供給等因素之地區差異所影響，發現這些經濟變數的相關性與房價相關係是有關聯的，特別是失業率方面。

中 文 關 鍵 詞 ： 漣漪效應、價動態相關、關聯結構、房價

英 文 摘 要 ： This project focuses on the dynamic changes of the housing price correlation in the United Kingdom. We use the copula method to estimate dynamic correlation coefficients (DCC) between ten regions and London in the last four decades, showing that the DCC generally increases during the economic downturns such as the early 1980s, early 1990s, and the 2008 global crisis. Between 1976 and 2015, we do not find structural breaks of the DCC. The effect of economic interdependence on housing price correlation is found in OLS models. Using Granger causality test, we also indicate that the interaction of housing prices will conversely affect the interaction of unemployment rate. Finally, the spillover effects of London's housing prices has been weakening to date.

英 文 關 鍵 詞 ： Ripple effect, dynamic correlation, copula, housing prices

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□執行國際合作與移地研究心得報告
□出席國際學術會議心得報告
□出國參訪及考察心得報告

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漣漪效應與區域房價動態相關之影響因素

Ripple Effect and Underlying Causes of Dynamic Correlation of Regional Housing Prices

摘要

本計畫研究區域間房價的動態互動關係以及漣漪效應的可能成因，選擇英國為分析之樣本國家。運用 Copula 模型所計算的動態相關係數分析英國倫敦地區與其他地區在過去四十年間的關係。發現地區間的關係多發生在經濟情況較差的階段，譬如 1980 年代初期、1990 年代初期與 2008 金融海嘯時期，在樣本期間內，倫敦與各地區房價動態相關係數並沒有結構性轉變，但卻有慢慢降低的趨勢。本研究也運用因果關係測試(Granger causality test)，分析各區房價動態關係是否受到人口、所得、失業率供給等因素之地區差異所影響，發現這些經濟變數的相關性與房價相關係是有關聯的，特別是失業率方面。

關鍵字：漣漪效應、動態相關、關聯結構、房價

ABSTRACT

This paper focuses on the dynamic changes of the housing price correlation in the United Kingdom. We use the copula method to estimate dynamic correlation coefficients (DCC) between ten regions and London in the last four decades, showing that the DCC generally increases during the economic downturns such as the early 1980s, early 1990s, and the 2008 global crisis. Between 1976 and 2015, we do not find structural breaks of the DCC. The effect of economic interdependence on housing price correlation is found in OLS models. Using Granger causality test, we also indicate that the interaction of housing prices will conversely affect the interaction of unemployment rate. Finally, the spillover effects of London’s housing prices has been weakening to date.

Keywords: Ripple effect, dynamic correlation, copula, housing prices

I. Introduction

Rising housing prices in a regional market will spread to other regions, and this phenomenon could be called ripple effect (Giussani, 1991). Specifically, the ripple effect is a distinct spatial pattern in the housing market. Housing prices rise first in a city, spread to an adjoining city, and then spread further out to the next city until this ripple reaches the borders of the country. According to the literature, U.K. might be the best sample to understand the ripple effect. Gray (2012) uses exploratory analysis to show that the patterns of housing prices in Britain between 1998 and 2005, which show a diffusion process from the Southeast region to other regions, clearly indicate a pattern of the ripple effect.

Numerous papers have discussed the possible driving forces of the interaction of housing prices (Meen, 1999; Zhu, Füss, and Rottke, 2013; Yunus and Swanson, 2013; Kallberg, Liu, and Pasquariello, 2014). Zhu et al. (2013) calculate economic interdependence among 19 metropolitan areas in the U.S., showing that strong comovement of housing prices also occurs between areas that share similar economic conditions. Yunus and Swanson (2013) point out that the co-integrate levels of regional per capita income and GDP are in enough to explain those levels of 9 housing markets in the U.S. Kallberg et al. (2014) decompose housing price index into fundamental and excess return, the portion of index that cannot be attributed to financial factors, indicating that the comovement among 14 metropolitan areas in the U.S. mostly comes from the fundamental portion rather than excess one.

This paper discusses the interdependence of housing prices in U.K. by the dynamic correlation between London and other ten regions from 1976Q1 to 2015Q1. Compared to prior studies mainly using the comovement between housing prices to

understand the driving forces of housing-price interdependence, we calculate time-varying correlation coefficients by copula method and document the following findings. First, the levels of housing price correlation generally are driven by geographic connection, and the trends of housing price correlation have a negative relationship with U.K. economy. Second, the housing price correlation between most regions and London do not exist structural breaks during the study period. Next, besides the geographic connection, economic interdependence also affects the housing price correlation. Finally, the interaction of housing prices will conversely drive the interdependence of labor market.

This paper provides the following contributions to the literature. First, Prior literature discusses ripple effect on the basis of a static correlation, but economic comovement should produce a wave over time rather than continue at a static level. With dynamic correlation coefficients, we comprehensively describe the dynamic patterns of housing price correlation from 1976 to 2015. We show that the housing price correlations on average are higher during the economic downturns such as the early 1980s, early 1990s, and the 2008 great recession. Consistent with Zhu et al. (2013) and Yunus and Swanson (2013) indicating the higher interaction between housing prices during the economic downturns in the U.S., we provide some evidence in U.K.

Second, this is the first paper empirically testing the determinants of housing price correlation in England. Compared to Zhu et al. (2013) and Kallberg et al. (2014) using the weight of economic interdependence or decomposition of housing prices to measure the effects of economic forces, we directly examine the relationship between housing price correlation and that of economic variables. We show that the economic

interdependence generally has a positive effect on the housing price correlation, while the high correlation of population may reflect low migration activities and decrease the housing price correlation.

Third, we test structural breaks of time-varying correlations. Compared to prior studies showing the structural breaks of housing price correlation in Singapore and the U.S., we do not find structural breaks from the housing price correlation between London and ten regions in U.K. (Liao, Zhao, Lim, and Wong, 2014; Kallberg et al., 2014). Therefore, the housing price correlation tends to be more stable in U.K.

Finally, we examine the causality relationship between housing price correlation and economic variables. In contrast to the literature predicting a one-way causality relationship between the economic interdependence and housing price correlation, the results show that the interaction of housing market can conversely affect the correlation of unemployment rate (Holmans, 1990; Meen, 1999; Zhu et al., 2013). Our findings also provide evidence of the effect of housing prices and supply on the labor market in an intra-region level (Saks, 2008; Sasser, 2010).

The remainder of the paper proceeds as follows. Section 2 introduces the related literature of ripple effect. Section 3 describes the research design and data. Section 4 presents the empirical analysis. Section 5 concludes this study.

II. Related literature of ripple effect

Long-run convergence of the regional housing prices

Among the studies discussing the ripple effect, a strand of papers tests the long-run convergence of the ripple effect (MacDonald and Taylor, 1993; Cook, 2003; Cook, 2005; Holmes and Grimes, 2008; Gray, 2012). MacDonald and Taylor (1993) adopt cointegration methodology and show numerous cointegrating relationships in

the U.K., but they also find weak evidence in other regions. Cook (2003) uses the asymmetric unit root tests to find the widespread convergence of housing prices in a number of regions of the U.K., suggesting that the failure of previous analyses to uncover convergence is due to an underlying asymmetry in the adjustment process being ignored. Cook (2005) further shows that the reversion to the equilibrium of regional housing prices occurs more rapidly when housing prices in the South of U.K. decrease relative to other regions.

Different to the previous literature, Holmes and Grimes (2008) calculate the first principal component based on regional-national housing prices differentials, showing that the stationary of this ratio implies the convergence of regional housing prices. Gray (2012) uses region-level data of Britain to analyze the pattern of the ripple effect, implying that spatial spillover of housing price growth is unlikely to work on interlocked markets suffering from obstacles to commuting and migration. In sum, existing studies have failed to reach a consensus on whether or not regional housing prices exhibit long-run convergence with each other (Holmes and Grimes, 2008).

Determinants of the ripple effect

Another strand of papers studies the determinants of the ripple effect, Meen (1999) greatly reviews the prior literature and proposes four possible explanations for the ripple effect. The first is migration; households living in a rising market might move to an adjacent city that has relatively lower housing prices, causing the raised prices to spread out to other cities (Giussani and Hadjimatheou, 1991; Thomas, 1993; Alexander and Barrow, 1994). The second is equity transfer; this supposes that house price is an indicator of equity, and the migrated purchasers bring greater buying power, forcing up prices in their target city (Muellbauer and Murphy, 1991). The third is

spatially limited arbitrage; arbitrageurs try to take profits from the price differential in neighboring markets, but various costs slow the process and create a pattern of prices similar to the ripple effect (Pollakowski and Ray, 1997). The final reason is the spatial patterns in the determinants of housing prices. Because economic activities first arise in one city and then spread out to others, housing price performance is a lagged movement causing similar ripple patterns to economic activities (Holmans, 1990).

After Meen (1999), several papers discuss the reasons for the ripple effect in U.S. Miao, Ramchander, and Simpson (2011) analyze the spatial dependence across 16 metropolitan statistical areas (MSAs) in the U.S., suggesting that both information diffusion and population migration might be the potential sources for the dependence. Zhu et al. (2013) highlights the importance of economic interdependence from the results of 19 MSAs, indicating that regional interdependence during the subprime period obviously increases. Kallberg et al. (2014) investigate the raw and excess comovement among 14 MSAs between 1992 and 2008, showing that comovements among housing markets are increasing and are mostly attributable to fundamental correlations.

Ripple effect in other countries

The ripple effect in other countries is also verified in some studies. In Asia, Chien (2010) employs the endogenous two-break LM unit test in Taiwan housing data and shows that the ripple effect exists in each city in Taiwan except Taipei City. Lee and Chien (2011) apply the panel seemingly unrelated regressions augmented Dickey-Fuller test, showing the dependence of stationarity properties of housing prices on the structure and properties of various regions in Taiwan. For instance, Lean and Smyth (2013) also find strong evidence of a ripple effect in Malaysia. Liao et al.

(2014) show evidence in Singapore indicating that foreign-liquidity shocks not only enhance housing prices in the central region but also induce a ripple effect of prices from the central city to the suburbs.

In North America and Africa, Gupta and Miller (2012a) apply various tools to test the ripple effect in eight Southern California MSAs, and they find that different specifications provide superior forecasts in the different MSAs. Gupta and Miller (2012b) estimate the average RMSE of different models to conclude a similar result from housing prices in Los Angeles, Las Vegas, and Phoenix. Balcilar, Beyene, Gupta, and Seleteng (2013) analyze the ripple effect in five MSAs in South Africa. From the results, it is apparent that ripple effects that originate in different places might result from different sized houses.

3. Research design and Data

3.1 Empirical design

This paper employs the following steps. We first conduct the augmented Dicky-Fuller unit root test to examine the stationarity of the housing price index (Dicky and Fuller, 1979). Then, we apply the copula method to obtain the dynamic correlation coefficients of housing price index between each region and London.[1] After obtaining the copula coefficients, we report the descriptive statistics and trends of these dynamic correlation coefficients, trying to paint a clearer picture of ripple effect.[2]

[1] We do not calculate the copula value between each pair of all eleven regions in U.K., because there are total 45 time-series of copula values that could mess the results. We instead estimate the housing price correlation between each region and London to reflect the relation between regions and economic center.

[2] If the ripple effect exists in the data, we should see that the dynamic correlation coefficients first increase around the regions adjacent to London in 1998, then in the South of UK, and finally in the North and North West of UK.

We further use the copula coefficients as dependent variables and employ several tests to amplify the literature. First, we test whether the dynamic correlation coefficients have existed structural breaks from 1976Q3 to 2015Q1, based on the methodology of Bai and Perron (1998). Second, we use Granger causality test to understand whether the interaction of housing prices also conversely affect the interaction of economic variables between regions (Granger, 1969). Finally, we test the determinants of the dynamic correlation coefficients by the following OLS model.

$$\rho(HP)_{xl,t} = \rho(UER)_{xl,t} + \rho(CP)_{xl,t} + \rho(INCOME)_{xl,t} + \rho(POP)_{xl,t} + Ex - post\ crisis_t + Ex - post\ crisis_t * \rho(X)_{xl,t} + MR_t + GDP_t + CPI_t + \varepsilon_t, \quad (1)$$

where $\rho(X)_{xl,t}$ is the dynamic correlation coefficients between X variable of x region and those of London; *UER* is unemployment rates; *CP* is construction permits; *INCOME* is personal income; *POP* is regional population; *GDP* is gross domestic product; *CPI* is consumer price index; *MR* is fixed mortgage rates; *Ex-post crisis* is a dummy variable of the after-crisis period, which equals one in year from 2009 to 2011.[3] Since the dynamic correlation coefficients generally drop after the 2008 global financial crisis, we use an indicator of after-crisis period and test whether the effects of different driving forces drop during this period.

3.2 Methodology

This paper applies the copula method to obtain the dynamic correlation and analyzes the trends in the correlation between regional housing prices. Sklar (1959) indicates that any bivariate CDF (or n-dimensional distribution) can be decomposed into two parts, the marginal distribution functions and the copula functions, the functions describing the dependence part of the distribution. Specifically, for any

[3] The data from 1977 to 2011 is used in Granger causality test and the OLS model, because the information of construction permits is available only from 1976 to 2011.

random variables $y_{1,t}$ and $y_{2,t}$ with marginal CDFs $F_1(y_{1,t})$ and $F_2(y_2,t)$, the values produced by CDFs will follow a uniform distribution regardless of the functional forms of CDFs. Thus, the following copula function C(.), which connects the two CDFs, exists

$$F(y_{1,t},y_{2,t})= C(F_1(y_{1,t}), F_2(y_{2,t})), \quad (2)$$

where the copula function C(.) estimates the dependence of these two CDFs, i.e., the function C(.) yields the joint distribution of function F(.). If the marginal CDFs are continuous, the corresponding copula in Equation (2) is unique.

The copula is a convenient tool to integrate bivariate distributions even when the distributions are unknown or extremely complex.[4] Additionally, there is concurrently a growing application of the time-varying copula method in housing market research, which shows that the copula is a decent tool for modeling housing prices (Zimmer, 2012, 2015). Zimmer (2012) indicates that jointly related asset prices may exhibit departures from normality, particularly in the tails, and he explores the housing price connection during the financial crisis using various copula specifications. Zimmer (2015) further employs the copula method in the multivariate GARCH model to verify the dynamic correlations between housing prices in four U.S. cities.

The essential problem with the copula method, however, is to choose a correct copula model that can accurately represent the dependent features of data (Coval, Jurek, and Stafford, 2009). If an incorrect copula is chosen, the joint distribution may be mischaracterized. To address this problem, we use Akaike information criterion (AIC) and Bayesian information criterion (BIC) coefficients to select the better model

[4] For a discussion of the literature and application of the copula-based method for economic and financial data, please refer to Patton (2006a, 2006b, 2012).

of housing data between the Gaussian copula and Student's t copula.[5] From the results shown in Appendix A, Gaussian copula generally outperforms Student's t copula, we therefore use Gaussian copula in the following empirical analyses.

3.3 Data description

We use several data sources. The basic dataset used in this paper is the quarterly seasonally adjusted National house price index from 1976Q1 to 2015Q1. We also collect several important determinants of regional housing prices that have been supported by prior studies. On the regional level, we obtain quarterly data such as unemployment rates (Johnes and Hyclak, 1999; Saks, 2008), population (Mankiw and Weil, 1989; Swan, 1995; Potepan, 1996), construction permits (Mikhed and Zemcik, 2009; Zhu et al., 2013), and personal income (Yunus and Swanson, 2013) between 1992 and 2012 from the Office for National Statistics. We further extend the sample period up to 1976 by manually collecting the annual values of these variables from *Regional Trends* magazine. In the macroeconomic level, we obtain gross domestic product (GDP) and consumer price index (CPI) from the Office for National Statistics, and the annual effective mortgage rate (MR) is from the Bank of England.

4. Empirical results

4.1 Trends in housing prices and stationarity

Table 1 describes the distribution of housing price index for each region during the past four decades. According to the results in Panel A, regions located in the south such as East, South East, and South West have the highest housing prices. In contrast, the regions located in the north including Yorkshire and The Humber, North East, North West, and Scotland on average have the lowest housing prices compared to

[5] We follow the models shown in Patton (2006a, 2006b) and Vogiatzoglou (2010) to estimate the dynamic Gaussian and Student's t copula.

other regions. We further apply logarithmic transformation and take the difference of first order to estimate the growth rate of all housing price indices. As shown in Panel B, the rank of growth rate among regions is similar to that of housing price index. The regions with high levels of housing prices usually have a high growth rate of housing prices.

[Insert Table 1 here]

Figure 1 further illustrates the time trends for the housing prices in each region. Most housing price indices have similar trends between 1976 and 2015. However, the difference in housing prices between London and other regions has been becoming larger after 1995. In 1995, close to those of South East and South West, the housing price index of London is 108.42. Then in 2007, after a long period with steady economic growth rate due to the reform of employment market, the housing price index of London is 440.50, which is much higher than the value 388.94 in South East. This gap shrinks a little bit during the 2008 global financial crisis, but it widens again and becomes even bigger after the recovery of the economy. In 2014, the housing price index of London is 586.62, which is almost 1.5 times of those of South West. To sum up, the ripple effect starting from London has been weakening to date because the increase in London's housing prices does not spread too much to other regions.

[Insert Figure 1 here]

To examine the stationarity of housing price indices in eleven regions, we employ the conventional augmented Dickey-Fuller unit root test and report the results in Table 2. After applying logarithmic transformation, all indices are stationary either we use the raw index values or we take first difference of the housing price index. To

reflect the return of housing prices, we use log-differenced housing price indices to calculate copula values, which shows the correlation of housing-price return between regions.

[Insert Table 2 here]

4.2 Static and dynamic correlation in each region

We calculate the traditional correlation between each region as a comparison with time-varying dynamic correlation. As indicated by the results in Table 3, most regions exhibit a higher correlation of house price indices with the regions adjacent to them. For example, from the results in the first column, the correlation between London and the other regions almost follows a monotonic decrease from regions in the South to that in the North. Consistent with Gray (2012) and Gupta and Miller (2012) showing that weak interaction between housing markets might be attributed to weak commuting ability, the geographic connection of regions seems to be an important driving force of the housing price correlation.

On the other hand, the correlations between regions in the Northern England are relatively weaker than those in the other regions. The average correlation among regions in the South such as London, South East, East of England, and South West is 0.81; the number in the Midlands such as East Midlands, West Midlands, and Wales is 0.74, while the number in the North including the other regions is 0.66. Since London is the core of UK, the economic connection of regions in the South is relatively stronger.

[Insert Table 3 here]

We further calculate the time-varying correlation coefficients. According to the descriptive statistics shown in Table 4, with time-series of housing price correlation, we can understand the distributions of housing price correlation between each region and London during the past four decades.

In general, the mean of correlation coefficients is similar to the static coefficients shown in Table 3, but few characteristics help us to understand more about the correlation between regions. First, although all regional housing markets have a positive relationship with London's housing market, some housing markets have had a negative relationship in the past four decades. Second, the correlations between London and the Northern regions are volatile. The standard deviation of these coefficients is much higher than those in the other regions. Third, the correlation coefficients of most housing markets have negative skewness, implying that correlation between regions and London generally is low but substantially increases in some period. Finally, correlation coefficients in most regions do not follow a normal distribution, according to the results of Jarque-Bera test.

[Insert Table 4 here]

We also present the time-series of copula values in Figure 2 showing few general tendencies of housing price correlations. First, most housing price correlations peak in the first half of the 1980s but dramatically drop after 1985 and touch the bottom around 1990. Next, the housing price correlations except those with North West and Wales largely decrease around 1995 and bounce back afterward. Finally, the housing price correlations significantly increase during the 2008 global crisis but drop afterward. For instance, compared with other regions, the housing price correlation between London and East of England bounces more frequent. Although the

correlation coefficients suddenly drop in 1982 Q1, 1988 Q1, 1993 Q4, and 2003 Q3, it quickly rebounds thereafter.

Overall, the trends of housing price correlation are negatively related to UK economy. According to the GDP growth rate shown as dashed line in Figure 2, few recessions such as the early 1980s recession, the early 1990s recession, and the great recession during the 2008 global crisis existed in the past four decades. The housing price correlations on average decrease during the expansions and rise when the economy falls down. On the other hand, we also find an obvious drop housing price correlation after 2008, which is consistent with the trends shown in Figure 1.

[Insert Figure 2 here]

4.3 Structural breaks test of dynamic correlation coefficients

In this subsection, we address whether there are structural breaks of housing price correlation existing from 1976 Q1 to 2015 Q1 by using the Bai-Perron breakpoints test (Bai and Perron, 1998). Among the housing price correlation between London and other ten regions, only the correlation with Wales exists structural break in 2008 Q2. Before 2008 Q2, the coefficient of copula value in *t-1* quarter is 0.94, implying a relatively persistent correlation between London and Wales. Between 2008 Q2 and 2015 Q1, the coefficient of copula value in *t-1* quarter becomes 0.64, showing a change in the correlation between these two regions. To sum up, there are no structural breaks found among the housing price correlation between London and most regions.

[Insert Table 5 here]

4.5 Determinants of housing correlation coefficients

We next examine the determinants of housing price correlation in U.K. Different to extant literature using comovement or cointegration analysis to test the relationship between housing prices and economic factors, we directly examine the determinants of dynamic correlation coefficients between regions (Zhu et al., 2013; Kallberg et al., 2014). Specifically, we pool all the time-varying copula values of regional economic factors between London and other regions from 1977 to 2011, and then we regress the copula values of housing prices on those values of other economic factors.[6]

Table 6 reports the results containing three alternative settings of the specification.[7] In terms of intra-region interaction, the correlations of the unemployment rate, construction permit, and personal income have a positive relation with the correlation between housing prices. On contrast, a higher correlation of population will accompany with a lower interdependence of housing prices. Out results, in general, support that the housing price correlation is likely to increase when interdependence of economy raises up (Zhu et al., 2013; Kallberg et al., 2014). Furthermore, since a higher correlation between populations may imply a weaker incentive of migration activities, we find a negative relationship between the comovement of the population and that of housing prices.

We next address the possible reason for the decrease in housing price correlation after the 2008 global crisis. As indicated in Figure 1 and Figure 2, London's housing

[6] Because the data of regional person income is only available from 1977 to 2011 in annual level, OLS models and Granger causality test are examined by annual data during this period.

[7] In column (1) of Table 6, we suppose a simultaneous relationship between the interaction of economic factors and that of housing prices. On contrast, a lead-lag relationship is assumed in column (2), which assumes that the economic interdependence leads housing price correlation. We finally employ the changes in correlations instead of levels of correlations to test how the changes in economic interdependence affect those in housing price correlation.

prices seem to spread less to other regions after the 2008 global crisis. To understand the reasons, we test whether the effect of economic factors becomes weaker after 2008 by adding an indicator *Ex-post crisis* which equals one during the period 2009 to 2011 in the model. The positive coefficient of *Ex-post crisis* found in column (1) shows that, other things being equal, the average housing price correlation between 2009 and 2011 is still higher than those from 1977 to 2008. However, the effect of economic factors has no significant change after the 2008 global crisis, according to the results of interaction variables.

To sum up, our results are in line with the findings of Zhu et al. (2013) and Kallberg et al. (2014), showing that economic interdependence is also important to housing price correlation. Since the data of regional construction permit and personal income are limited to the period from 1977 to 2011, we do not find a significant change in the effect of economic interdependence from 2009 to 2011.

[Insert Table 6 here]

4.4 Causality relationship among housing prices and other economic factors

Finally, we test the causality relationship among regional economic factors. The extant literature generally shows that the economic interdependence between regions is an important force leading the housing price connection (Holmas, 1990; Meen, 1999; Zhu et al., 2013; Kallberg et al., 2014). However, the correlation of housing prices could also conversely affect labor migration (Johnes and Hyclak, 1999; Saks, 2008; Sasser, 2010). Saks (2008) indicates that the increase in housing supply constraints can force out poorer households and then impact labor markets. Sasser

(2010) shows that the effect of housing affordability on migration has risen during the period 1997 through 2006 in the U.S.

With the time-series of housing price correlation, we are able to test the causality relationship between housing prices and other economic factors. The results of Granger causality test are shown in Table 7. Generally, the correlation of unemployment rate granger causes the correlation of housing prices, housing supply, and personal income. The correlation of population also leads the correlation of other factors except for unemployment rate. On the other hand, according to the results of column (2), we find evidence showing that the correlation of housing prices and housing supply can conversely lead the correlation of labor market.

Consistent with Saks (2008) and Sasser (2010), we find the effect of housing prices and supply on the labor market in an intra-region level by using the time-varying correlation coefficients between regions. We also add to the extant literature about the ripple effect by showing that the interaction of housing market can conversely affect the economic connection (Holmans, 1990; Meen, 1999; Zhu et al., 2013; Kallberg et al., 2014).

[Insert Table 7 here]

5. Conclusion

This paper explores the dynamic changes of the housing price correlation in the United Kingdom from 1976 to 2015. Using the copula method to estimate the time-varying correlation coefficients of housing prices between ten regions and London, we show that the trends of housing price correlation generally are negatively related to U.K. economy. During the last four decades, only the housing price

correlation between London and Wales exists structural break in 2008 Q2, while there are no structural breaks found in other regions. With the time-series of correlation coefficients, we also test the determinants of housing price correlation and find a positive relationship between the economic interdependence and the housing price correlation. Finally, the housing price correlation has two-way causality relationship with the interaction of labor market. The housing price correlation is driven by but also drives the correlation of unemployment rate.

The research offers insights to the literature. Compared with the extant literature using static correlation coefficients, we calculate time-varying correlation coefficients which provide a clearer picture of the changes in correlation (Gray, 2012). With correlation between regions in U.K. from 1976 to 2015 containing the downturn period up to the early 1980s, we provide a clear trend showing the negative relationship between correlation coefficients and economy (Miao et al., 2011; Zhu et al., 2013; Yunus and Swanson, 2013). We test the determinants of housing price correlation and corroborate the findings using cointegration analysis (Zhu et al., 201; Kallberg et al., 2014). We also examine the structural breaks of housing price correlation and find that the interaction of housing market can conversely affect the correlation of labor market (Holmas, 1990; Meen, 1999; Saks, 2008; Sasser, 2010).

Some further directions might be interesting for future research. From the trends of housing price indices and correlation coefficients, we find that the increase in London's housing prices does not spread too much to other regions after the 2008 global crisis. We use an indicator to capture the period from 2009 to 2011 and test whether the effects of economic factors on housing price correlation become weaker after 2008, but we do not find a significant change in those effects. Because the data

of regional construction permit and personal income are limited to the period from 1977 to 2011, with a longer data, it will be interesting to understand why the ripple effect starting from London has decreased after 2008.

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Table 1: Summary statistics of regional housing price indices

	Region										
	London	EAST	SE	SW	EM	WM	Wales	YH	NW	NE	Scotland
Panel A: Raw housing price index											
Mean	206.9025	169.6503	182.6677	170.9908	159.8756	148.0992	143.2533	144.7312	137.3908	133.5899	131.3476
Median	133.4903	123.8585	129.7893	120.0965	119.7708	112.0871	103.5885	108.0350	104.4526	102.4292	100.9474
Maximum	610.5968	384.6785	432.9201	390.7877	349.7366	316.6305	320.0378	318.6236	307.8240	294.4709	290.6071
Minimum	21.93434	21.91666	22.08399	21.24192	21.70923	19.13100	22.73384	23.90014	17.99438	20.84695	23.5669
Std. Dev.	161.8412	115.5185	129.7107	122.5907	110.3671	100.3726	98.08965	95.36703	95.47181	89.90084	85.1072
Observations	157	157	157	157	157	157	157	157	157	157	157
Panel B: Log-differenced housing price index											
Mean	0.0213	0.0183	0.0191	0.0186	0.0178	0.0179	0.0163	0.0160	0.0176	0.0165	0.0156
Median	0.0215	0.0177	0.0199	0.0201	0.0180	0.0163	0.0114	0.0171	0.0162	0.0150	0.0137
Maximum	0.1115	0.1392	0.1085	0.1503	0.1554	0.1656	0.1432	0.1306	0.1077	0.1259	0.0922
Minimum	-0.0640	-0.1023	-0.0626	-0.0747	-0.0617	-0.0566	-0.0937	-0.0804	-0.0601	-0.0713	-0.0706
Std. Dev.	0.0337	0.0368	0.0332	0.0329	0.0319	0.0317	0.0349	0.0353	0.0297	0.0350	0.0280
Observations	156	156	156	156	156	156	156	156	156	156	156

Panel A and Panel B report the summary statistics of raw housing price indices and log-differenced housing price indices from 1976Q1 TO 2015Q1, respectively. EAST is East of England; SE is South-East; SW is South-West; EM is East Midlands; WM is West Midlands; YH is Yorkshire and The Humberside; NW is North-West; and NE is North-East.

Table 2: ADF unit root tests of regional house prices indices

	Ln(HPI)	*ΔLn(HPI)*
	(1)	(2)
London	-6.788874***	-7.228913***
East of England	-7.270413***	-7.158123***
South East	-5.804777***	-6.124066***
South West	-4.129548***	-6.723399***
East Midlands	-6.502157***	-5.890577***
West Midlands	-7.091988***	-4.737102***
Wales	-4.884115***	-5.475566***
Yorkshire and The Humberside	-7.284084***	-7.338543***
North West	-3.426865***	-6.308013***
North East	-4.194346***	-3.982829***
Scotland	-9.829876***	-3.968998***

This table reports the results of augmented Dickey-Fullers (ADF) unit root tests of all regional housing price indices (*HPI*). Logarithmic transformation applies to all housing price indices; First order of difference is further taken on logged housing price indices in column (2). *** stand for significance at the 1% level.

Table 3: Pearson correlation coefficients of housing price index between each region

	London	EAST	SE	SW	EM	WM	Wales	YH	NW	NE	Scotland
London	1.0000										
East of England	0.7440	1.0000									
South East	0.8613	0.8537	1.0000								
South West	0.7483	0.7964	0.8748	1.0000							
East Midlands	0.6702	0.7459	0.7575	0.7410	1.0000						
West Midlands	0.6267	0.7132	0.7745	0.8144	0.7948	1.0000					
Wales	0.6234	0.5959	0.6561	0.6212	0.7280	0.6825	1.0000				
YH	0.5722	0.5766	0.6615	0.6319	0.7723	0.7349	0.7633	1.0000			
North West	0.5219	0.5479	0.6165	0.6094	0.6892	0.7135	0.7384	0.7530	1.0000		
North East	0.3594	0.4378	0.4483	0.4290	0.5838	0.5444	0.5449	0.6003	0.6470	1.0000	
Scotland	0.3929	0.4763	0.4563	0.5215	0.5064	0.5368	0.5077	0.6181	0.6506	0.6661	1.0000

This table reports the Pearson correlation coefficients of housing prices among eleven regions in U.K. EAST is East of England; SE is South-East; SW is South-West; EM is East Midlands; WM is West Midlands; YH is Yorkshire and The Humberside; NW is North-West; and NE is North-East.

Table 4: Descriptives of copula values between each region and London

	Region									
	East and South			Midlands and Wales			Yorkshire and The Humber, North, and Scotland			
	EAST	SE	SW	EM	WM	WALES	YH	NW	NE	SCOTLAND
Panel A: Basic information										
Mean	0.7476	0.8562	0.7629	0.6861	0.6491	0.6369	0.5901	0.5420	0.3862	0.3860
Median	0.7514	0.8580	0.7656	0.6786	0.6610	0.6646	0.6014	0.5490	0.3465	0.3958
Maximum	0.8823	0.9190	0.8885	0.8104	0.8478	0.8997	0.8371	0.8335	0.7737	0.8651
Minimum	0.5456	0.6698	0.4594	0.5442	0.4558	0.2977	0.2368	-0.0641	-0.0966	-0.2595
Std. Dev.	0.0605	0.0332	0.0661	0.0464	0.0940	0.1668	0.1293	0.1258	0.2331	0.2431
Sum	116.6302	133.5735	119.0110	107.0312	101.2541	99.3571	92.0576	84.5535	60.2500	60.2227
Panel B: Shape of distribution										
Skewness	-0.6335	-1.5114	-1.5166	0.2170	-0.1136	-0.4964	-0.1819	-1.0913	0.0064	-0.4021
Kurtosis	4.1106	9.2636	7.8997	3.2286	1.9379	2.2009	2.2706	7.1382	1.7166	2.8266
Panel C: Test of normal distribution										
Jarque-Bera	18.4521	314.4042	215.8512	1.5636	7.6677	10.5575	4.3188	142.2788	10.7074	4.3993
Probability	0.0001	0.0000	0.0000	0.4576	0.0216	0.0051	0.1154	0.0000	0.0047	0.1108
Observations	156	156	156	156	156	156	156	156	156	156

This table reports the summary statistics of copula values of housing prices between each region and London. EAST is East of England; SE is South-East; SW is South-West; EM is East Midlands; WM is West Midlands; YH is Yorkshire and The Humberside; NW is North-West; and NE is North-East.

Table 5: Structural breaks test of copula values between each region and London

Region	Time points of breaks
East of England	No breakpoints
South East	No breakpoints
South West	No breakpoints
East Midlands	No breakpoints
West Midlands	No breakpoints
Wales	**2008 Q2**
Yorkshire and The Humberside	No breakpoints
North West	No breakpoints
North East	No breakpoints
Scotland	No breakpoints

This table reports the results of structural breaks test of copula values of housing prices between ten regions and London from 1976Q1 to 2015Q1. The Bai-Perron breakpoints test using sequential L+1 breaks vs. L is used to determine breaks (Bai and Perron, 1998).

Table 6: Determinants of housing correlation coefficients between regions

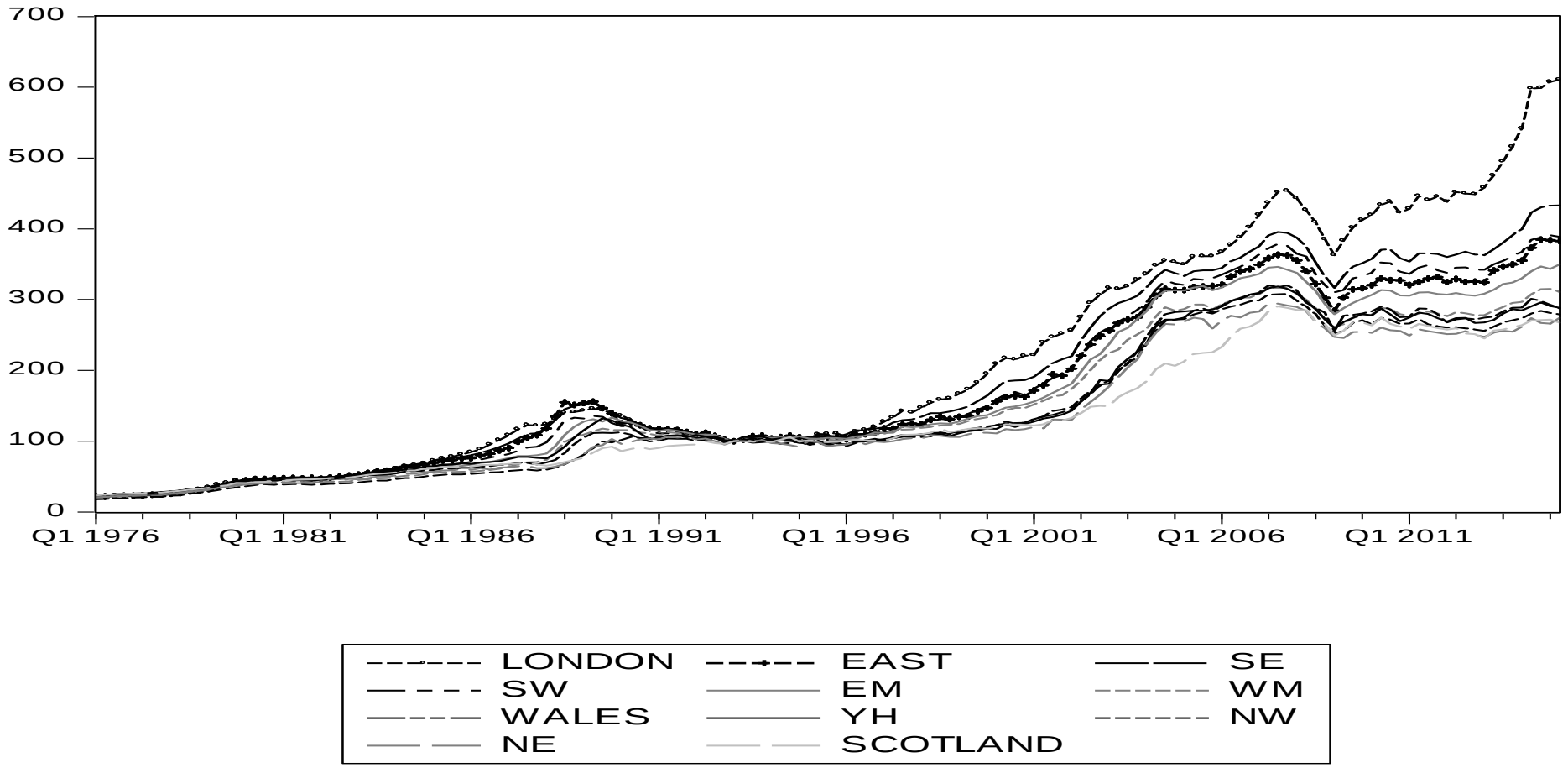
Dependent variable	$\rho(HPI)_{i,t}$	$\rho(HPI)_{i,t}$	$\Delta\rho(HPI)_{i,t}$
Independent variable	$\rho(X)_{i,t}$	$\rho(X)_{i,t-1}$	$\Delta\rho(X)_{i,t-1}$
	(1)	(2)	(3)
$\rho(UER)_{i,t}$	0.8966***	0.9288***	0.9288***
	(0.0000)	(0.0000)	(0.0000)
$\rho(POP)_{i,t}$	-0.2365***	-0.2480***	-0.2480***
	(0.0000)	(0.0000)	(0.0000)
$\rho(CP)_{i,t}$	0.1186***	0.0809**	0.0809**
	(0.0009)	(0.0248)	(0.0248)
$\rho(INCOME)_{i,t}$	0.2791***	0.1815**	0.1815**
	(0.0002)	(0.0185)	(0.0185)
$Ex-post\ crisis_t$	0.7122*	0.6687	0.6687
	(0.0949)	(0.2531)	(0.2531)
Ex-post crisis * $\rho(UER)$	-0.3137	-0.7624	-0.7624
	(0.5942)	(0.2741)	(0.2741)
Ex-post crisis * $\rho(POP)$	0.1918	0.1171	0.1171
	(0.1153)	(0.4493)	(0.4493)
Ex-post crisis * $\rho(CP)$	0.0461	-0.0725	-0.0725
	(0.7545)	(0.7202)	(0.7202)
Ex-post crisis * $\rho(INCOME)$	-0.5537	-0.0334	-0.0334
	(0.4016)	(0.9660)	(0.9660)
GDP_t	-0.4933	-0.6571	-0.6571
	(0.2611)	(0.1181)	(0.1181)
CPI_t	0.7215***	0.6338***	0.6338***
	(0.0001)	(0.0013)	(0.0013)
MR_t	-0.1605**	-0.0410	-0.0410
	(0.0172)	(0.5424)	(0.5424)
Constant	-0.1506*	-0.0735	-0.0735
	(0.0896)	(0.4257)	(0.4257)
F-statistic	26.1139	21.51945	21.5195
Adj. R^2	0.4634	0.42074	0.4207
N	350	340	340

This table reports the results of OLS models regressing the copula values of housing prices between ten regions and London from 1977 to 2011. $\rho(X)$ is the dynamic correlation coefficients between X variable of each region and those of London; *UER* is unemployment rate; *POP* is population; *CP* is construction permits; *INCOME* is personal income; *Ex-post* is an indicator variable that equals to one for period from 2009 to 2011, otherwise equals to zero; *GDP* is gross domestic product; *CPI* is consumer price index; and *MR* is interest rate of 5-year fixed rate mortgage. P-value is reported in parentheses; ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

Table 7: Granger causality tests among copula values of regional economic factors

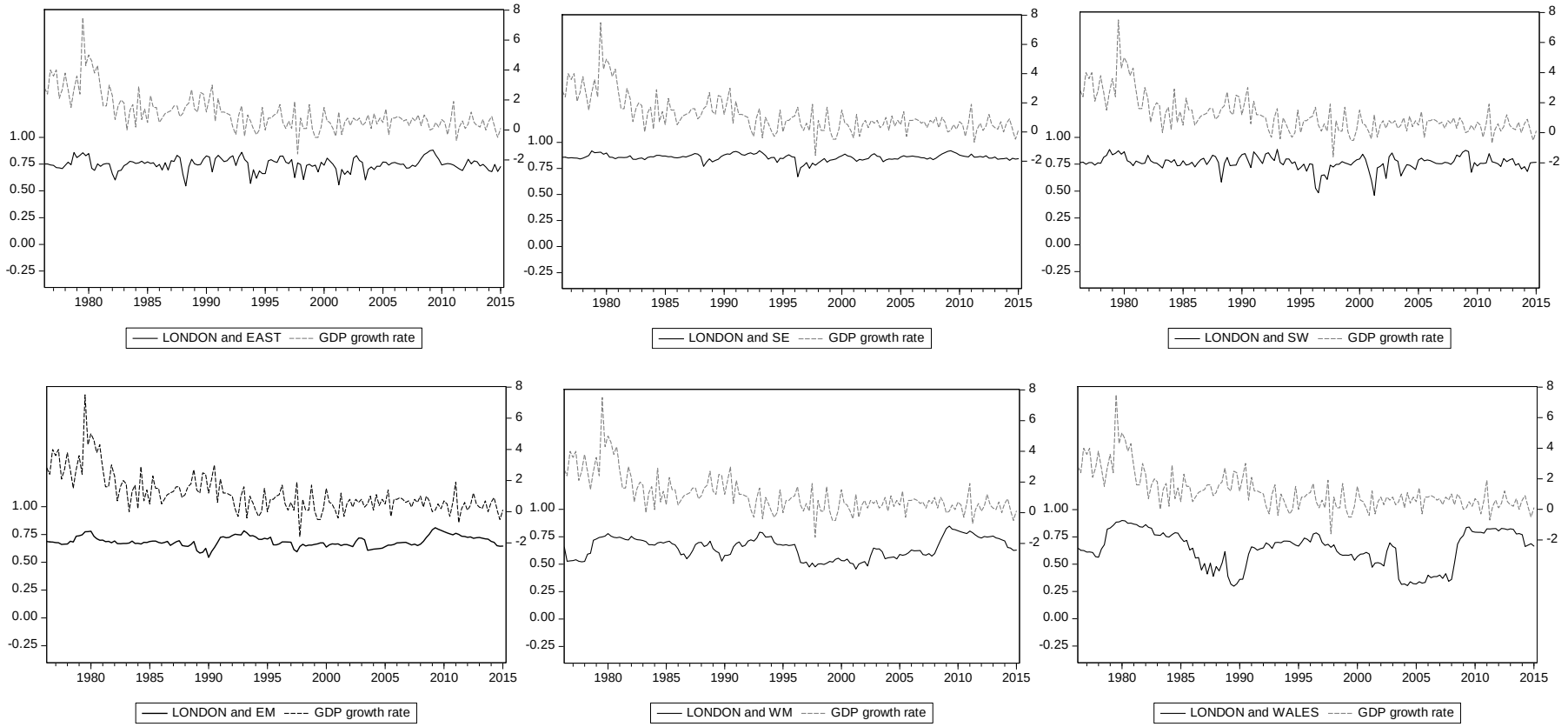
	Dependent variables				
	$\rho(HPI)_t$	$\rho(UER)_t$	$\rho(POP)_t$	$\rho(CP)_t$	$\rho(INCOME)_t$
	(1)	(2)	(3)	(4)	(5)
$\rho(HPI)_{t-1}$	-	6.9410***	2.2000	0.8616	2.3465
		(0.0084)	(0.1380)	(0.3533)	(0.3533)
$\rho(UER)_{t-1}$	5.0062**	-	0.7320	6.7100***	3.7266***
	(0.0253)		(0.3922)	(0.0096)	(0.0096)
$\rho(POP)_{t-1}$	12.6300***	1.1761	-	3.2392*	0.0066*
	(0.0004)	(0.2781)		(0.0719)	(0.0719)
$\rho(CP)_{t-1}$	1.9552	3.0691*	1.7717	-	0.8041
	(0.1620)	(0.0798)	(0.1832)		(0.7676)
$\rho(INCOME)_{t-1}$	2.5229	0.1151	0.0491	0.0873	-
	(0.1122)	(0.7344)	(0.8246)	(0.7676)	
N	340	340	340	340	340

This table reports the results of VAR(1) Block Exogeneity Wald Tests between copula values of regional economic factors from 1977 to 2011. *HPI* is housing price index; *UER* is unemployment rate; *POP* is population; *CP* is construction permits; and *INCOME* is personal income. Chi-square value is reported, and we report p-value in parentheses. ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.



This figure presents time trends of housing price indices of eleven regions in U.K. from 1976Q1 to 2015Q1. EAST is East of England; SE is South-East; SW is South-West; EM is East Midlands; WM is West Midlands; YH is Yorkshire and The Humberside; NW is North-West; and NE is North-East.

Figure 1: Time trends of housing prices



This figure presents time-series of copula values between ten regions and London from 1976Q1 to 2015Q1. GDP growth rate is marked by dashed line as a comparison. EAST is East of England; SE is South-East; SW is South-West; EM is East Midlands; WM is West Midlands; YH is Yorkshire and The Humberside; NW is North-West; and NE is North-East.

Figure 2: Time trends of copula values of housing prices between each region and London

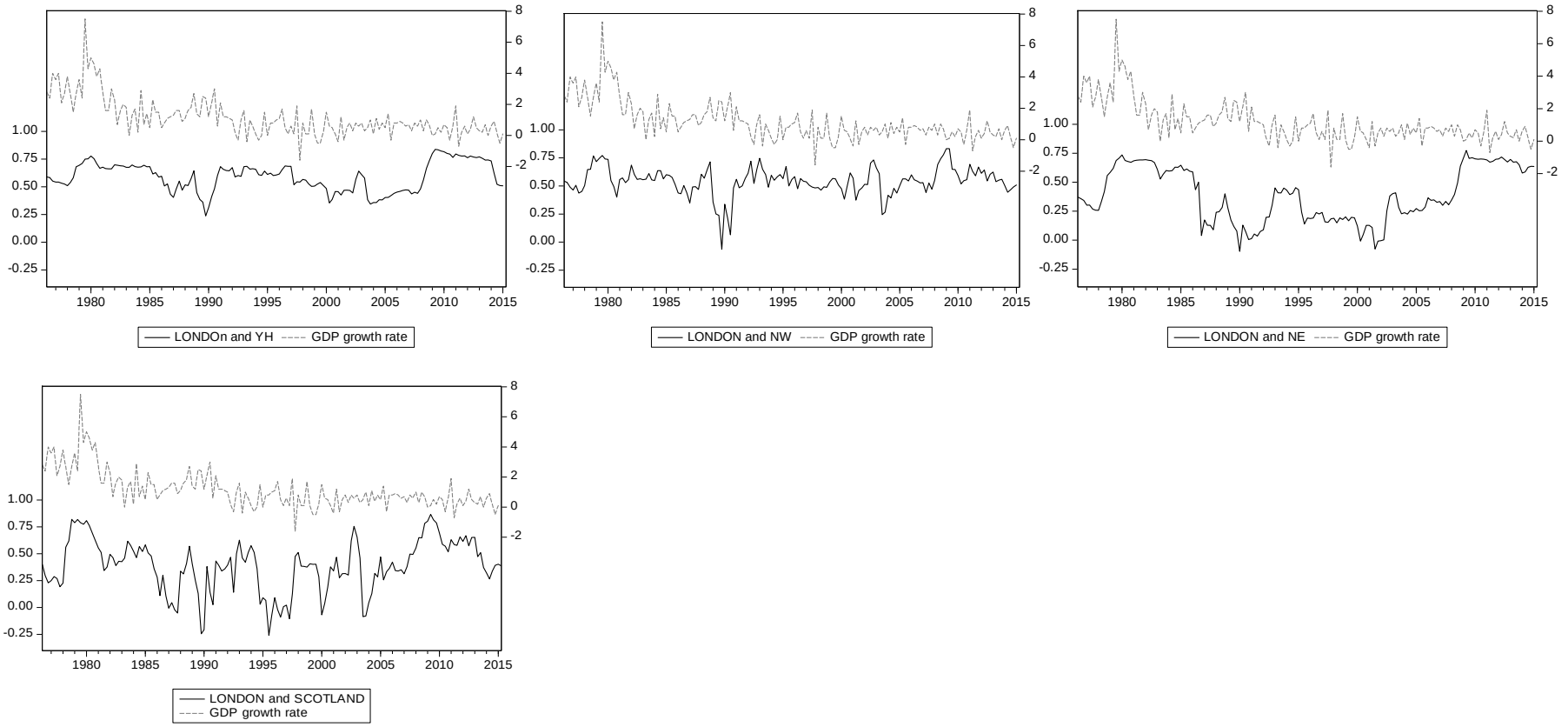


Figure 2: Continued

Appendix A: AIC and BIC for copula values between each region and London

	Gaussian copula		Student's T copula	
	AIC	BIC	AIC	BIC
LON_EAST	-1.31E+02	-1.25E+02	-129.2154	-120.0658
LON_SE	-207.6968	-201.5971	-209.8900	-200.7404
LON_SW	-142.1756	-136.0761	-140.1635	-131.0139
LON_EM	-97.1019	-91.0022	-103.6303	-94.4808
LON_WM	-87.3424	-81.2427	-85.67933	-76.5298
LON_WALES	-91.7208	-85.6211	-91.2232	-82.0736
LON_YH	-66.3574	-60.2577	-71.5368	-62.3872
LON_NW	-64.0329	-57.9332	-64.1308	-54.9813
LON_NE	-28.3440	-22.2443	-26.8952	-17.7457
LON_SCOTLAND	-38.4331	-32.3334	-36.4193	-27.2697

This appendix reports the results of AIC and BIC test for Gaussian and Student's T copula values between each region and London from 1976Q1 to 2015Q1. LON_EAST is the copula values between London and East of England; LON_SE is the copula values between London and South-East; LON_SW is the copula values between London and South-West; LON_EM is the copula values between London and East Midlands; LON_WM is the copula values between London and West Midlands; LON_YH is the copula values between London and Yorkshire and The Humberside; LON_NW is the copula values between London and North-West; and LON_NE is the copula values between London and North-East.

Appendix B: Sensitivity of settings for testing the determinants of housing correlation coefficients between regions

Dependent variable	$\Delta\rho(HPI)_{i,t}$	$\rho(HPI)_{i,t}$
Independent variable	$\Delta\rho(X)_{i,t}$	$\Delta\rho(X)_{i,t}$
	(1)	(2)
$\rho(UER)_{i,t}$	0.5586***	-0.0190
	(0.0000)	(0.8308)
$\rho(POP)_{i,t}$	0.0619***	0.0178
	(0.0000)	(0.3528)
$\rho(CP)_{i,t}$	0.0006**	0.0014
	(0.0248)	(0.1167)
$\rho(INCOME)_{i,t}$	0.1350**	-0.0030
	(0.0185)	(0.4423)
$Ex-post\ crisis_t$	0.2347	0.1494***
	(0.2531)	(0.0010)
Ex-post crisis * $\rho(UER)$	-0.2643	0.3344
	(0.2741)	(0.7490)
Ex-post crisis * $\rho(POP)$	0.6605	-0.2127
	(0.4493)	(0.7961)
Ex-post crisis * $\rho(CP)$	-0.0056	-0.0033
	(0.7202)	(0.7944)
Ex-post crisis * $\rho(INCOME)$	0.2103	-0.0056
	(0.9660)	(0.9298)
GDP_t	-0.0032	0.0022
	(0.1181)	(0.6753)
CPI_t	0.1292***	0.0000
	(0.0013)	(0.9990)
MR_t	0.0046	0.0008
	(0.5424)	(0.2590)
Constant	-0.2250	0.6064***
	(0.4257)	(0.0000)
F-statistic	0.05578	1.9843
Adj. R^2	-0.0345	0.0337
N	340	340

This appendix reports the results of OLS model regressing the copula values of housing prices between ten regions and London from 1977 to 2011. $\rho(X)$ is the dynamic correlation coefficients between X variable of each region and those of London; *UER* is unemployment rate; *POP* is population; *CP* is construction permits; *INCOME* is personal income; *Ex-post* is an indicator variable that equals to one for period from 2009 to 2011, otherwise equals to zero; *GDP* is gross domestic product; *CPI* is consumer price index; and *MR* is interest rate of 5-year fixed rate mortgage. P-value is reported in parentheses; ***, **, and * stand for significance at the 1%, 5%, and 10% levels, respectively.

105年度專題研究計畫成果彙整表

計畫主持人：陳明吉						**計畫編號：**105-2410-H-004-143-	
計畫名稱：漣漪效應與區域房價動態相關之影響因素							
成果項目						量化	單位	質化 （說明：各成果項目請附佐證資料或細項說明，如期刊名稱、年份、卷期、起訖頁數、證號...等）
國內	學術性論文	期刊論文				0	篇	
		研討會論文				0		
		專書				0	本	
		專書論文				0	章	
		技術報告				0	篇	
		其他				0	篇	
	智慧財產權及成果	專利權	發明專利	申請中		0	件	
				已獲得		0		
			新型/設計專利			0		
		商標權				0		
		營業秘密				0		
		積體電路電路布局權				0		
		著作權				0		
		品種權				0		
		其他				0		
	技術移轉	件數				0	件	
		收入				0	千元	
國外	學術性論文	期刊論文				0	篇	
		研討會論文				1		2017 Annual Conference of Asian Real Estate Society
		專書				0	本	
		專書論文				0	章	
		技術報告				0	篇	
		其他				0	篇	
	智慧財產權及成果	專利權	發明專利	申請中		0	件	
				已獲得		0		
			新型/設計專利			0		
		商標權				0		
		營業秘密				0		
		積體電路電路布局權				0		
		著作權				0		
		品種權				0		

		其他	0		
	技術移轉	件數	0	件	
		收入	0	千元	
參與計畫人力	本國籍	大專生	0	人次	
		碩士生	0		
		博士生	0		
		博士後研究員	0		
		專任助理	0		
	非本國籍	大專生	0		
		碩士生	0		
		博士生	0		
		博士後研究員	0		
		專任助理	0		
其他成果 （無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。）					

科技部補助專題研究計畫成果自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現（簡要敘述成果是否具有政策應用參考價值及具影響公共利益之重大發現）或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估
   ■達成目標
   □未達成目標（請說明，以100字為限）
   　□實驗失敗
   　□因故實驗中斷
   　□其他原因
   說明：

2. 研究成果在學術期刊發表或申請專利等情形（請於其他欄註明專利及技轉之證號、合約、申請及洽談等詳細資訊）
   論文：■已發表　□未發表之文稿　□撰寫中　□無
   專利：□已獲得　□申請中　■無
   技轉：□已技轉　□洽談中　■無
   其他：（以200字為限）
   本研究完成計畫，達成目標，已發表在2017 Asian Real Estate Society Annual Conference，但未來仍會繼續深入，在發表過程中仍會進行修正，以更提升最終研究計畫品質

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性，以500字為限）
   區域間不動產市場會存有連動波及關係，此連動波及關係的範圍與強弱是學術界與政府都關心的議題，此連動波及的範圍與強弱也會隨時間變化，特別是台灣區域均衡雖是政府之政策目標，但這些年來區域發展不均日趨嚴重，造成房市也朝向不均衡方向發展，區域間房價之間的連動關係也因此在變化之中，本研究由於需要較長的時間樣本，採用英國為分析標的，而英國與台灣同樣為較小國家，同為有一個核心城市，故英國研究會有參考價值，特別對台灣投資者、建商與政府對不動產市場做決策有很大參考價值，此為本計劃貢獻之處。

4. 主要發現
   本研究具有政策應用參考價值：□否　■是，建議提供機關內政部,經濟部,財政部,
   （勾選「是」者，請列舉建議可提供施政參考之業務主管機關）
   本研究具影響公共利益之重大發現：■否　□是
   說明：（以150字為限）