A Changepoint Analysis of UK House Price Spillovers

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Abstract

We study spillovers between regional housing markets in the UK in the period 1973 to 2020. The analysis is based on a vector autoregressive model that allows for structural breaks in its parameters at unknown times. In particular, we allow for distinct breakpoints in the conditional mean, variance and correlation parameters, which enables us to distinguish different spillover channels. Based on the resulting piecewise constant model we compute the spillover index by Diebold and Yilmaz. We find significant time variation of the spillover index that indicates a decreasing role of London for the rest of the country, but that also indicates reduced contagion risk and the existence of the North-South divide that declined later in the sample. Furthermore, a central role of the Midlands is demonstrated.

JEL Classification: C32; G01; R10; R31

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1 Introduction

The US subprime mortgage crisis and subsequent global financial crisis have renewed the interest among researchers to analyze the dynamics in the housing market, an integral part of the overall economy. Aggregate economic conditions, coupled with observable and unobservable local factors, the quality of public facilities and neighborhood characteristics, play a role in determining housing market dynamics. Conversely, conditions in the housing market exert their influence on long-term financial arrangement of economic agents, on the objectives of policy makers and on the risk management practice of financial institutions.

The contribution of the housing market to the overall economic performance in the UK is substantial, which underlines the importance of studying the UK housing market. The value added of the real estate sector amounted to 6% of GDP in 1990 and went up to 12% in 2013, according to IMF (2014). Pinter (2015) documents a −72% correlation between the HP-filtered real house prices and the unemployment rate between 1972Q1 and 2013Q3. Notably, over the past 30 years, UK real house prices have increased the most, compared to other OECD countries. Over this period, real house prices have increased by 0.96% in the UK per quarter, on average, compared to 0.35% in OECD countries and 0.32% in EA15 countries. Furthermore, house prices in the UK have been a lot more volatile when compared with other advanced economies.[1]

According to IMF (2014), both the duration and the amplitude of the of the UK housing cycles have increased significantly during the 1997−2013 period compared to the 1980−1996 period. In the past decades, the UK has experienced significant crises in the property market followed by recessionary episodes. For example, real property prices increased by around 6% and 9% in quarter two and three of 1988, respectively, and then declined by around 3% during the 1990−1992 period. Similarly, real house prices increased by around 3.9% during 2001−2002, before they experienced their sharpest decline of around 6.5% in 2008:Q3, following the US subprime crisis.

An emerging strand of the past literature tries to examine the dynamics of real estate to focus on regional variation, where region refers to sub-national geographical areas (see the editorial discussion in Derudder and Bailey, 2021). In this line of research, the first group of existing studies (Deng et al., 2019 and Funderburg, 2019) have analysed the role of public infrastructure on residential developments whereas Valadkhani et al. (2017) have examined the role of seasonality as an additional factor to explain regional house prices. The second group (Mohino and Urena, 2020, Palomares-Linares and van Ham, 2020, and Tammaru et al., 2020) have explored the linkage between regional unemployment, income inequality, and mobility with

[1] Authors' calculation using OECD Analytical House Price Data Base. EA15 refers to Euro area of fifteen countries.

regional house prices. The possible existence of spatial interdependence has been recognised by Funderburg (2019) and Lerbs and Oberst (2014). The third set of existing studies have explored how regions and regionality emerge by examining real estate geographies; see Gray (2018) and Tsai (2015). The last strand of the existing literature points out an increasing level of systemic risk either by investigating the dynamic linkage of regional house prices (Zhang and Fan, 2019), or by directly exploring the relationship between house prices and share prices at the regional level (Bissoondeeal , 2021). Our paper complements the last two strands of the literature by exploring the heterogeneous diffusion process while examining the dynamic linkage of regional house prices in UK. However, to study the dynamic evolution of spillover across regions, we distinguish between abrupt changes in contemporaneous linkages, changes in the dynamic transmission mechanism, and changes in volatility, which has not been considered in the existing literature.

In this paper we analyze regional UK house price indices covering different regions in England, as well as Northern Ireland, Wales and Scotland using a Vector autoregressive (VAR) model that allows for multiple structural breaks in its parameters, which are estimated using the methods developed in Qu and Perron (2007). Based on this model we compute the spillover index suggested by Diebold and Yilmaz (2009, 2012), which is based on the forecast error variance decomposition and is a popular measure for spillovers. Time variation in this index is captured by the structural breaks in the VAR model parameters, which, in contrast to the commonly used rolling window approach, has the advantage of ensuring statistical significance of the changes over time and allow for an interpretation of the changepoints in terms of economic conditions. Our contribution is as follows: first, we differentiate between breaks in contemporaneous dependence, breaks in volatility, and breaks in dynamic transmission mechanism represented by the conditional mean parameters of the VAR; see Blatt et al. (2015). Second, instead of treating break dates as exogenous, we treat them as endogenous (i.e. data driven). Third, we do not assume the structural breaks in the model parameters for the conditional mean, the volatility and the contemporaneous correlation to occur at the same dates, an advantage of using the methods by Qu and Perron (2007). In the contagion literature, typically breaks in volatility represent the occurrence of a crisis, whereas increases in dependence are interpreted as contagion, which are assumed to occur simultaneously. However the transmission of interdependence could occur with a time lag and an assumption of coincidence between volatility and correlation changes would undermine the presence of the dynamic spillovers (Candelon and Manner, 2010). Finally, we consider a fully multivariate model of regional house prices which enables us to capture the transmission mechanism across regional house price more precisely compared to a pairwise analysis, as there could be not only direct but also an indirect spillover effects from one region to another. Additionally, analyzing the structural breaks in a multivariate model has the advantage of more reliable breakpoint detection. Bai et al. (1988), Groen et al. (2011) and Qu and Perron (2007) demonstrate the superior performance of detecting a structural break in a multivariate system compared to a univariate model.

Our results confirm the presence of three common breaks of the conditional mean occurring at 1984:Q2, 1993:Q4 and 2003:Q2, whereas for the standard deviation, the common break dates are 1987:Q1, 1996:Q4 and 2006:Q3, respectively. The breaks in the correlation matrix are dated 1984:Q1, 1993:Q4, and 2008:Q3, although these are not statistically significant. These breaks can be associated with important developments in the UK housing market and with regional economic trends. The spillover analysis after allowing for distinct breaks in mean, variance and in the correlation matrix depicts the time varying path of the spillover index. The net and directional spillover show the existence of different house price clubs. We observe heterogeneous impact of breaks in different regions to some extent indicating the presence of the North-South divide. We find a decreasing role of London as spillovers from there to others have reduced, and for the South the net spillover becomes negative after 1996 with the exception of the period 2004-2008. The Midlands, the North and Scotland have been net receivers of spillovers for most parts of our sample, but this has increased after the global financial crisis in 2008. The spillover from Wales and Northern Ireland to others have significantly increased after 2006-2007.

The rest of the paper is organized as follows. Section 2 briefly discusses additional existing literature. The data and econometric methodology is presented in Section 3. Section 4 presents and discusses the empirical results. Section 5 concludes the paper.

2 Literature Review

Regional housing price dynamics and dependencies can be studied to obtain a better understanding of the developments in the UK housing market as a whole. A large disparity exists among regional house price indices, as price changes are not consistent across regions and occur in different ways and at different scales. Still, fluctuations disperse both through centrifugal and centripetal forces, which generates uneven distributions of economic activity (Fujita and Krugman, 2004) and socio-spatial patterns (Filton, 2010) within and between different localities. In the UK, the Northern part lags the developing and upbeat South, both socially and economically. This so-called 'North-South divide' (Hincks et al., 2014) is also present in the housing market as another feature of uneven spatial development in the UK. House prices roared much more in the South than in the North.

Modeling regional variation in housing market dynamics is crucial as movements in price in one region of the housing markets spills over spatially and thereby affecting the aggregate market (Holly et al., 2010, Brady, 2011 and Campbell et al., 2011). A shock in house prices in one region can spread across different regions through different factors: migration, arbitrage and equity transfer generating spillover across regional housing prices, a phenomenon known as the 'ripple effect'. Following the seminal work by Meen (1996), and Meen (1999), several studies have examined the existence of the 'ripple effect'. An incomplete list includes Ashworth and Parker (1997), Peterson et al. (2002), Cook (2003), Holmes and Grimes (2008), Holmes et al. (2011), and Barros et al. (2011). Using UK data, Drake (1995) documents the existence of a ripple effect occurring earlier in an extensive way in the Southeast of England compared with other regions of the UK. According to Meen (1996, 1999), housing prices in the Southeast lead the prices in the other UK regions showing a dissimilar spatial pattern over time: rising first in a cyclical upswing in the Southeast region and then spreading out over the rest of the country. However MacDonald and Taylor (1993) portray the existence of weak segmentation and Cook (2005) documents the presence of an asymmetric ripple effect: the housing prices revert to equilibrium faster when housing prices in the south of England decreases relatively to those of other regions and vice−versa. Tsai (2015), using the spillover index as developed by Diebold and Yilmaz (2009, 2012), reports that house prices in London do not influence the housing markets of other regions and during the 2008 global financial crisis the decline in housing prices in the Northern regions is as significant as those in the overall market. However the house prices in the Northern regions did not ricochet like the overall market did after 2009, reinforcing the existence of the 'North-South' divide.

Existing research has also examined the spatial diffusion and adjustment of house prices over time. Can (1990) uses a hedonic model of house prices where house price is being modeled as functions of different characteristics while incorporating both spatial spillover effects and spatial parametric shift. Fingleton (2008) exploits spatial GMM estimator for modeling house price with spatial moving average errors. Evidence in favor of 'ripple effect' in Netherlands is obtained by van Dijk et al. (2011). Holly et al. (2010) examine the evolution of real house prices and real disposable incomes across the 48 U.S. States and obatin statistically significant evidence of autoregressive spatial effects in the residuals of the cointegrating relations. Holly et al. (2011), using UK regional data, find that the impact of a shock decays more slowly along the geographical regions compared to the decay along the time dimension. For example, the effects of a shock to London on itself are largely dissipated after two years whereas the effects of the same shock on other regions takes much longer to die away, the further the region is from London. Cook (2012) documents evidence in favour of β-convergence across the regions in the downswings occurring in London and therefore presence of period dependent convergence. Gray (2018) shows that the housing price space in the UK has two super-regions: one in the north and one in the south overlapping with the midlands of England. The relationship between the stock market and UK house prices is studied in Bissoondeeal (2021) showing heterogeneous responses in regional variation, and that London prices have influenced house prices in other regions.

3 Data and Methodology

3.1 Data

Quarterly data on the regional house price index (HPI) is taken from the UK mortgage lender Nationwide. This data set is also used by Gray (2018), Cook and Watson (2016), and Abbott and De Vita (2013). The data covers the period 1973:Q4 to 2020:Q4 and is seasonally adjusted.[2] We use the data from 10 regions in England, namely, North (NOE), Yorkshire & the Humber (YAH), North West (NOW), East Midlands (EMI), West Midlands (WMI), East Anglia (EAE), South West (SOW), South East (SOE), Greater London (LON), and outer Metropolian (OME). These regions were aggregated into the following four regions by computing population weighted averages (using population values from the year 2019) of their components: North (NOE, YAH, NOW), Midlands (EMI, WMI), South (EAE, SOW, SOE, OME) and London.[3] Northern Ireland, Scotland and Wales were also included in the analysis giving us a total of seven regions. To obtain real housing price index (RHPI) values, we deflate the HPI by consumer price index obtained from International Financial Statistics−International Monetary Fund and we compute log-returns to obtain stationary data. As exogenous variables to control for economic conditions in the UK we considered first differences in unemployment and interest rates (10-year government yields), as well as the log difference of real GDP, all downloaded from the FRED database. Ideally one should use these macroeconomic variables at the regional level, but these were not available for our sample period and data frequency.

Table 1 reports the descriptive statistics of the RHPI return series. As expected, London and the South are the two UK regions with the highest average housing price returns followed by the Midlands. Scotland has the lowest returns, which are similar to the ones in Northern Ireland, Wales and the North of England. The dispersion

[2] Nationwide house prices are mix adjusted - i.e. tracking a representative house price over time rather than the simple average price. For details see: https://www.nationwide.co.uk/-/media/MainSite/documents/about/house-price-index/nationwide-hpi-methodology.pdf.

[3] Instead of using the population weighted averages, we could also use principal component analysis for aggregation of the English regions as done in, e.g., Yang et al. (2018). The resulting aggregated indices were basically equivalent with a correlation of 0.99 with the weighted ones.

Table 1: Descriptive Statistics

Region	Mean	Std. Dev	Skewness	Kurtosis	Unit Root Test
North	0.37	2.68	0.74	4.46	<0.001
South	0.55	2.96	-0.17	3.52	<0.001
Midlands	0.45	2.87	0.60	6.22	<0.001
London	0.72	3.34	-0.25	2.98	<0.001
Wales	0.35	3.26	0.46	4.96	<0.001
Scotland	0.31	2.29	-0.12	3.53	<0.001
N.Ireland	0.36	3.84	-0.30	4.92	<0.001

Note: Descriptive statistics for the log returns of the house price indices (multplied by 100). The unit root test result are based on the Phillips-Perron test performed on the price series in levels.

as measured by the standard deviation is largest in Northern Ireland followed by London and Wales. Scotland has the lowest standard deviation. The house price returns are positively skewed in three out of seven regions and there is some evidence of mildly leptokurtic distributions as evidenced by the kurtosis being larger than 3. The excess kurtosis for London is close to zero, but the returns of the Midlands have a kurtosis of over 6. The last column of Table 1 reports the results of unit root tests for the original series. The unit root hypotheses for the original real price index cannot be rejected for any of the regions, but the return series do not have a unit root (details available upon request).

3.2 Econometric model and tests for structural breaks

Let $\boldsymbol{Y}_t = [Y_{1,t}, \ldots, Y_{n,t}]'$ denote the vector of returns of the regional house price index (RHPI) for regions 1 to n and $t = 1, \ldots, T$. We model $\boldsymbol{Y}_t$ using a vector autoregressive model of order p with exogenous variables (VARX):

$$\boldsymbol{Y}_t = \boldsymbol{B}_{0,t} + \sum_{i=1}^{p} \boldsymbol{B}_{i,t}\boldsymbol{Y}_{t-i} + \boldsymbol{B}_{x,t}\boldsymbol{X}_{t-1} + \boldsymbol{u}_t, \tag{1}$$

where $\boldsymbol{B}_{i,t}$ are the coeffient matrices of the lagged values and $\boldsymbol{u}_t = [u_{1,t}, \ldots, u_{n,t}]$ is a vector of mean zero innovations with potentially time-varying covariance matrix $\boldsymbol{\Sigma}_t = \boldsymbol{S}_t\boldsymbol{R}_t\boldsymbol{S}_t$. $\boldsymbol{X}_{t-1}$ denotes the first lag of the vector of exogenous variables with coefficient matrix $\boldsymbol{B}_{x,t}$ (in our case changes in unemployment, interest rates, and log differences of real GDP). The lag length p is selected by minimizing the bayesian information criterion (BIC). The covariance matrix is decomposed into the correlation matrix $\boldsymbol{R}_t$ with typical element $\rho_{ij,t}$ and the diagonal matrix $\boldsymbol{S}_t$ containing the standard deviations $\sigma_{i,t}$. All parameters of the model are allowed to be time-varying and we have a piecewise constant model in mind, where the parameters are subject to structural breaks at unknown points in time. Furthermore, breaks in the different types of model parameters are not assumed to occur at the same time, but there are three types of structural breaks: in the conditional mean, the error variance, and the error correlation. The breakpoints in $\boldsymbol{B}_t$, the matrix collecting the coefficient matrices $\boldsymbol{B}_{i,t}$ for $i = 1, \ldots, p$ and $\boldsymbol{B}_{x,t}$, the ones in $\boldsymbol{S}_t$ and the ones in $\boldsymbol{R}_t$ are determined sequentially. To be specific, we test the following null hypothesis:

$$H_0^B : \boldsymbol{B}_1 = \boldsymbol{B}_2 = \ldots = \boldsymbol{B}_T$$

against

$$H_1^B : \boldsymbol{B}_1 = \ldots = \boldsymbol{B}_k \neq \boldsymbol{B}_{k+1} = \ldots = \boldsymbol{B}_T.$$

Similarly, conditional on the breakpoints in $\boldsymbol{B}_t$, we test

$$H_0^S : \boldsymbol{S}_1 = \boldsymbol{S}_2 = \ldots = \boldsymbol{S}_T$$

against the alternative of structural breaks in volatility analogously to H_1^B. Finally, conditional on the breaks in $\boldsymbol{B}_t$ and $\boldsymbol{S}_t$ we test the constancy of the correlation matrix:

$$H_0^R : \boldsymbol{R}_1 = \boldsymbol{R}_2 = \ldots = \boldsymbol{R}_T.$$

The sequence of null hypotheses is tested using the methods developed in Qu and Perron (2007) and we refer the interested reader to this paper for technical details. In particular, the tests are based on the supremum of likelihood ratio statistics based on the multivariate normal distribution for general multivariate regression models and the method of Qu and Perron (2007) allows for breakpoints in the regression parameters and the covariance matrix of the errors. The approach does not assume normality or even i.i.d.'ness of the errors, but the underlying assumptions allow for fat-tailed and heteroscedastic errors. See also Bataa et al. (2013) and Blatt et al. (2015) for details on the testing algorithm and applications thereof. Multiple breaks can be identified using the algorithm in Bai and Perron (2003) by testing for structural breaks in the subsamples between initially identified breaks. We allow for up to three structural breaks in each type of parameters.

This approach allows for a large degree of flexibility in the time-variation of the parameters and this instability in the model specification is permitted in order to capture changes in the dynamics between the housing price series over time. In contrast to a rolling window approach typically used in the literature to allow for time variation, our approach has the advantage of ensuring that the changes in the parameters are statistically significant and are not merely caused by sampling variation. No prior knowledge of the events that may cause the model instability is assumed. In correspondence with the break testing literature, the minimal regime length between breaks of the same individual parameter is set to the integer value of $[0.1 \cdot T]$, where T is the full sample length. Testing for breaks in a multivariate system has the advantage of giving more precise estimates of their unknown locations and potentially more powerful tests; see Bai et al. (1988). At the same time, the limited amount of time periods available requires adequate restrictions in the sense of assuming all parameters of the same type (cond. mean, volatility, and correlation) to break at the same point in time. After testing for and dating the breaks, the model is estimated subject to the changepoints. Based on this piecewise constant parameter model, the spillover approach developed by Diebold and Yilmaz (2009, 2012) and also employed by Tsai (2015) in a similar context is applied to the housing price data. The h-step ahead forecast error variance decomposition is denoted by λ_{ij}^h and it represents the fraction of the forecast error variance in variable i due to shock to variable j. These are normalized to ensure $\sum_{j=1}^n \lambda_{ij}^h = 1$ and $\sum_{i=1}^n \sum_{j=1}^n \lambda_{ij}^h = n$. Formally, the total spillover index is defined as

$$TS^h = 100 \cdot \frac{\sum_{i=1}^n \sum_{j=1,j\neq i}^n \lambda_{ij}^h}{\sum_{i=1}^n \sum_{j=1}^n \lambda_{ij}^h}. \tag{2}$$

It measure the fraction of overall forecast error variance that is due to shocks to other markets. Directional spillover indexes are defined as the spillover transmitted from region i to all other regions,

$$DS_{\leftarrow i}^h = 100 \cdot \frac{\sum_{j=1,j\neq i}^n \lambda_{ji}^h}{n}, \tag{3}$$

and as the spillover received by i from the other regions,

$$DS_{\rightarrow i}^h = 100 \cdot \frac{\sum_{j=1,j\neq i}^n \lambda_{ij}^h}{n}. \tag{4}$$

Combining the two, the net spillover by region i is given by

$$NS_i^h = DS_{\leftarrow i}^h - DS_{\rightarrow i}^h. \tag{5}$$

Together with the outcomes of structural break testing, the spillover analysis provides a rich, dynamic analysis of how shocks in some UK regions are propagated to other regions.[4]

[4]Note that we rely on the generalized forecast error variance decomposition as in Diebold and Yilmaz (2012), which does not identify structural shocks with a clear economic interpretation. An alternative would be the approach suggested in Yang et al. (2021). However, due to our rather small sample this approach is not feasible for us.

4 Empirical application

4.1 Structural break testing

We begin by estimating the VARX model (equation (1)) for the RHPI returns. The lag-length of the VAR model is selected using the Bayesian Information Criterion and we select a lag-length of one. Changes in unemployment, interest rates, and log-difference in real GDP are included as exogenous variables to control for the general economic conditions in the UK that can be expected to be factors driving house prices. Given our sample size of $T = 188$ observations, we choose the resulting minimal regime length to be $[0.1 \cdot T] = 19$ and a maximum of $m = 3$ breaks in each type of parameter: mean ($\boldsymbol{B}$), variance ($\boldsymbol{S}$) and correlation ($\boldsymbol{R}$). A 12-step-ahead (3-years of quarterly data) forecast error variance decomposition is computed for the spillover analysis.[5]

To determine the common break dates that are common within mean, variance and the correlation matrix, we adhere to a sequential procedure based on the methods for multivariate models developed in Qu and Perron (2007) and the algorithm for estimating the locations of the breaks in Bai and Perron (2003). Our procedure can be described in three steps: Step 1 searches for a maximum of three breaks simultaneously in all $n + pn^2 + 3n$ (= 77 in our case with $n = 7$, $p = 1$ and 3 exogenous variables) conditional mean parameters $\boldsymbol{B}$. In step 2, conditional on break points in the conditional mean, we look for simultaneous breaks in $n = 7$ standard deviations contained in $\boldsymbol{S}$ and then finally step 3 investigates a maximum of three simultaneous co-breaks in the correlation matrix of $n(n-1)/2 = 21$ coefficients in $\boldsymbol{R}$ conditional on the breaks in mean and standard deviations (for details see Blatt et al., 2015 and Qu and Perron, 2007).

Table 2 describes the results for the conditional mean and variance parameters. The table contains the estimated break dates for the parameters and the changes in the estimated parameters. For the conditional mean parameters we report the sums over the changes of the respective coefficients to summarize the information contained in the large number of coefficients. For the conditional mean parameters, three breaks occur at 1984:Q2, 1993:Q4 and at 2003:Q2. Similarly for error variance, the break dates are estimated at 1987:Q1, 1996:Q4 and at 2006:Q4, respectively. The estimated break dates in the different parameter types clearly differ, but all three are not too far apart from each other. The direct interpretation of the parameter changes is not straightforward, as there is a lot of heterogeneity in the conditional mean parameters and the changes in volatility reflect only changes in the error variance, but the unconditional variance of the house price index returns themselves

[5] The results for other forecast horizons, such as 5 or 20 steps, yield virtually identical results. Detailed results are available upon request.

Table 2: Break analysis for mean and standard deviation

Mean parameter breaks				Standard deviation breaks			
max LR	446.78			max LR	88.93		
Critical value	250.58			Critical value	58.07		
p-value	< 0.001			p-value	0.0101		
Dates	1984 Q2	1993 Q4	2003 Q2	Dates	1987 Q1	1996 Q4	2006 Q4
Covariates	change	change	change	Series	change	change	change
$Const$	-0.005	0.101	-0.089				
$North_{t-1}$	-1.864	0.781	-1.022	$North$	0.102	0.057	-0.693
$South_{t-1}$	0.049	-1.366	-2.306	$South$	-0.195	-0.521	0.005
$Midlands_{t-1}$	2.870	-0.421	2.016	$Midlands$	-0.020	-0.595	-0.370
$London_{t-1}$	-4.414	1.187	0.922	$London$	-0.423	-0.557	0.574
$Wales_{t-1}$	3.310	-0.160	0.588	$Wales$	-0.384	0.232	-0.182
$Scotland_{t-1}$	1.403	-1.277	1.997	$Scotland$	-0.121	-0.048	-0.653
$N.Ireland_{t-1}$	-0.181	0.069	1.092	$N.Ireland$	-0.088	-0.150	1.900
$Unemp_{t-1}$	0.198	0.466	-0.375				
IR_{t-1}	-0.058	0.156	-0.004				
GDP_{t-1}	-0.517	-1.142	1.496				

Note: Test results, estimated break dates and corresponding changes in coefficients for the conditional mean parameters (left panel) and the standard deviations (right panel). For breaks in the mean regression, changes in coefficients are summarized for each regressor listed in the first column: The shifts in the estimated regression coefficients are sums across all equations.

is a function of $\boldsymbol{B}_t$ and $\boldsymbol{S}_t$. In this section we mainly focus on interpreting the estimated break dates. The interplay of the different model parameters is better reflected in the spillover indices that we analyze in detail in the next section.

The break in conditional mean at 1984:Q2 as well as that in standard deviation (1987:Q1) could be attributed to the deregulation in housing and financial markets along with the general performance of the economy. Between 1984:Q1 and 1989:Q1, real GDP increased by almost 20%; unemployment had also fallen during the same period. The statutory Housing Act of 1980 enabled council tenants with the right to buy even with a discount: from 33% with three years' residence to a maximum of 50% after twenty years' residence. This was also accompanied by available mortgage facility from local authorities. The minimum lending rate of Bank of England's was abolished in 1981 and banks were allowed to compete with building societies for housing finance. The investment income surcharge was abolished in 1985. The house price to earnings ratio reached a peak in the middle of 1988 in southern parts; it did continue to increase in the North, Yorkshire and Humberside, and in Scotland until 1989. In some cases the increase continued into 1991.

The unsustainable high growth led to inflation and the UK has joined the Exchange Rate Mechanism in 1990. The value of the Pound started deteriorating and the government has increased the interest rate to protect the value of Pound. Increased interest rate coupled with high unemployment led to unaffordable mortgage payments, increase in default rate and drop in house prices. Arrears and repossessions had increased leading to a phenomenon known as negative equity. UK had withdrawn from the exchange rate mechanism of the European Community in

September 1992. Market interest rates fell from 10% to 6%, leading to reductions in mortgage rates to under 8%. This is also being observed in positive coefficient of lagged interest rate. Ordinary share and bond returns fell to very low levels which led investors to turn their attention towards real estate. The year 1996 was being earmarked as the end of the recession and the beginning of recovery for the national housing market. Combination of these factors led to a break in conditional mean in 1993:Q4 along with that in standard deviation in 1996:Q4.[6]

Although the housing demand has been continuously increasing due to the demographic trend and rising incomes, this has been unmatched by rising housing supply. Over the ten years to 2002, output of new homes was 12.5% lower than for the previous ten years accompanied by worsening affordability especially among the first-time buyers. The Bank of England lowered the base rate from 6% to 4% between 2001-2003. Low interest rates, strong levels of employment and the availability of credit led to an increase in residential values. The break in conditional mean at 2003:Q2 could have been triggered by these events. During 2005-2007, global credit availability, less strict lending criteria for borrowers and new mortgage techniques emerged to satisfy market demand. The long-term housing shortage and upward trend in house prices created an optimistic environment among the first-time buyers as well as for the investors and speculators to provide funds for home construction, and for lending to potential borrowers. The banks had given loans to the 'sub-prime' borrowers. With high default rates on their mortgages among these 'sub-prime' borrowers, the banks ended up with bad debts. This has contaminated the global financial system and banks stopped lending to each other creating the credit crunch. Lack of mortgages results in stagnation of markets and the selling of properties took place at a lower price.

Table 2 reveals the heterogenous impact of breaks in different regions. We observe that for the break in standard deviation at 1987:Q1, volatility has decreased in all regions except in North. The same pattern has been observed for the 1996:Q3 except for North and Wales. However with the 2006:Q4 break in standard deviation an almost exactly opposite pattern occurs: regions in the Midlands, North including Scotland had witnessed a fall in volatility whereas in volatility has increased in South and in London. Northern Ireland has also witnessed a surge in volatility following the break in 2006:Q4. This to some extent indicates the presence of the 'North−South divide'. For the break in mean, the North, London and Northern Ireland shows similar pattern: the break in 1984:Q2 is associated with a fall in the VAR coefficients where as for the other two breaks, it shows an increase. Interestingly, for the South, for the last two breaks in mean, we see a decrease in the coefficients.

[6] The Association of Residential Letting Agents (ARLA) and four lenders had launched the "buy-to-let initiative" in September 1996 which promoted investment in property.

For the Midlands, Wales and Scotland, we observe a fall in case of the second break (1993:Q4) and a rise for the other two breaks.

Table 2 also reports the coefficients associated with the exogenous variables in our VAR framework.[7] At the first two breaks, the coefficient associated with lagged changes in unemployment increase on average, whereas the last break is associated with an average decrease in the coefficients. The coefficient associated with lagged growth in GDP is in line with unemployment (given that increases in GDP mean positive developments), so its role decreases twice and then bounces back. The effect of interest rates goes down at the first break, increase in the second and after that remains almost constant.

Table 3 reports the corresponding structural break test results in error correlation, conditional on the mean and variance breaks. For each pair, the table reports the initial correlation, the changes at the corresponding dates given in the last column, and the level of correlation after the last break. We note that we were not able to reject the null hypothesis of stable correlation coefficients between the series. This can be explained by the large number of 21 correlation coefficients and the corresponding low power of the test for a sample size of $T = 188$. However, when we impose the existence of three structural breaks in the correlation coefficients we observe quite sizable changes in correlation in 1984:Q1, 1993:Q4, and in 2008:Q3. The spillover analysis in the next section shows that some of these breakpoints lead to quite notable changes in the spillover indices and therefore we decided to continue the analysis imposing the breaks in correlation. In terms of interpretation, we note that the error correlations capture contemporaneous co-movements in the house price index returns, which cannot be captured by the (reduced form) VAR coefficients. Not surprisingly, all correlations but one (London vs. Scotland prior to 2008) are positive at all times and lie between -0.05 and 0.92. The first break in 1984:Q1 basically coincides with the first break in conditional mean and hence is subject to a similar interpretation. It is associated with a decrease in all pairwise correlations, some of those being very sharp drops. The most notable drops were relative to Northern Ireland. But also the correlation between North and South clearly decreased, a sign of decoupling of the North from the South and of decreased instantaneous spillovers. The second break date in the correlation 1993:Q4 is exactly same as the break in mean and coincides with the increased interest rate, high unemployment and withdrawal from the exchange rate mechanism of the European Community. Here, 16 out of 21 correlations had decreased. The sharp decrease in correlations of pairs involving London stands out and indicates decreasing spillovers from there. Finally, the last break in 2008:Q3 is obviously coinciding with the global financial crisis and Great Recession witnessing an increase in 17 out of 21 correla-

[7] We thank two anonymous referees for this suggestion.

Table 3: Correlation breaks

Correlation breaks								
	North	*South*	*Midlands*	*London*	*Wales*	*Scotland*	*N.Ireland*	
		0.89	0.79	0.87	0.85	0.79	0.85	
		−0.17	−0.21	−0.11	−0.09	−0.09	−0.48	Q1 1984
North	1	−0.03	+0.25	−0.50	−0.17	−0.07	−0.21	Q4 1993
		−0.07	−0.02	+0.27	+0.11	−0.12	+0.27	Q3 2008
		0.61	0.80	0.53	0.70	0.51	0.43	
			0.80	0.92	0.89	0.87	0.81	
			−0.09	−0.02	−0.07	−0.22	−0.59	Q1 1984
South		1	+0.03	−0.20	−0.32	−0.19	+0.13	Q4 1993
			+0.03	+0.14	+0.19	+0.04	+0.12	Q3 2008
			0.76	0.85	0.68	0.51	0.47	
				0.72	0.70	0.63	0.70	
				−0.09	−0.11	−0.35	−0.59	Q1 1984
Midlands			1	−0.30	−0.07	+0.34	+0.10	Q4 1993
				+0.26	+0.20	−0.11	+0.27	Q3 2008
				0.59	0.73	0.50	0.48	
					0.90	0.82	0.73	
					−0.18	−0.19	−0.42	Q1 1984
London				1	−0.42	−0.59	−0.02	Q4 1993
					+0.33	+0.33	+0.17	Q3 2008
					0.63	0.37	0.47	
						0.79	0.69	
						−0.18	−0.50	Q1 1984
Wales					1	−0.30	−0.12	Q4 1993
						+0.04	+0.42	Q3 2008
						0.35	0.50	
							0.78	
							−0.42	Q1 1984
Scotland						1	−0.41	Q4 1993
							+0.33	Q3 2008
							0.27	
N.Ireland							1	

Note: Estimated break dates and corresponding changes in the error correlation coefficients.

tions. Most notably, the correlations versus London increased strongly, as did the correlation of Northern Ireland with all regions.

We observe that the average correlation between the regions has decreased in most cases over the sample period. For example, the correlation between North and South has decreased from 0.89 to 0.61, between North and London from 0.87 to 0.53. The correlation between Midlands and North as well as between Midlands and South remains almost at the same level (pre-1984 and post-2008). The correlation between London and any other regions of UK had fallen throughout our sample. Holly et al. (2011) documents that before 2008 London house prices were linked to other financial centres, and the post-2008 era should see stronger links between global financial centres and therefore weaker correlations with North. Our results demonstrate that this has started occurring even before the global financial crisis. On the other hand, we observe that the change in the correlation associated with the break emanating from the global financial crisis has made the correlation coefficients between London and other regions of UK increase. Tsai (2015) demonstrates that the difference in house prices between the northern and southern regions of the UK would increase each time a new financial crisis occurs. Our results show that this is happening with London but not so with the South: the change in correlation between South and other parts of UK is positive, but it is negative with the North.

Between 1984:Q1 and 1993:Q4, the correlation between Midlands & North, Midlands & Scotland and Midlands & Northern Ireland increases and it is almost the same before 1984 and after 2008 between Midlands & North, and between Midlands & Scotland. The correlation between Midlands and Wales shows an interesting pattern. Although between 1984 & 1993, and between 1993 & 2008 it decreased, after 2008 it increased again. The positive change in the correlation coefficient outweighs the negative change, thereby making the correlation between these two regions increase slightly. This finding corroborates Gray (2018) and Montagnoli and Nagayasu (2015) implying that Midlands and North including Scotland may form the augmented northern super-region.

Regarding the correlation between Midlands with South, we observe that the correlation has remained almost same before 1984 and after 2008 with a fall in correlation associated with the first break of 1984:Q1. The change in correlation between London and Midlands after the break in 2008:Q4 is 0.26, but was negative corresponding to the other two breaks. Our results thus indicate a distinction between London and South facing dynamics of the Midlands: in the South the values are much higher throughout the sample. This is in contrast to Gray (2018) and we attribute this to allowing for structural break in the dynamics of house prices relationship.

It is noticeable that the dependence between the house price returns has mostly increased at the break in 2008 coinciding with the global financial crisis, which can be interpreted as contagious transmission between the regions. Of the smaller number of correlation shifts that are negative, none are large enough to cause negative correlation coefficients, or even a correlation value below 0.27. In general, the structural break of 1984:Q1 itself is mostly associated with a de-escalation of the co-movement relative to the early part of the sample.

Interpreting the correlation shifts and their respective dates we need to keep in mind that these are conditional on the shifts in the conditional mean and variance parameters. The spillover analysis in the next section sheds light on the interplay of these shifts, which are difficult to interpret by themselves. We interpret the identified shifts in the following way. Increases in the spillover index are called "spillover contagion", which is more of a dynamic form of contagion that typically takes some time to materialize. This differs from "shift contagion" when the contemporaneous correlation increases, which is immediate. In the next sub-section, we present results from the spillover analysis.

4.2 Spillover analysis

In this section, we present the results from various spillover analysis following Diebold and Yilmaz (2009, 2012). First, we consider the total spillover index using a 12-step-ahead forecast error variance decomposition corresponding to three years. We estimate the total spillover index for each region (transmitting or receiving) excluding each own variance share. We consider two VAR models: one without any breaks and the other with distinct breaks in mean (**B**), variance (**S**) and in the correlation matrix (**R**). This allows for a large degree of flexibility in the time-variation of the spillover index and an interpretation of the three distinct channels for its changes. Figure 1 depicts our findings. The spillover index without any breaks is around 72% across different regions in UK. With common breaks within **B**, **S** and **R**, the spillover shows a different pattern: it was above 80% until 1985, then experiences a sharp fall in 1985 to less than 70%, and decreases further to less than 65% in 1994. The spillover index started to increase after 2008 above 75% and remains there at the end of the sample. Our results thus shows the importance of consideration of breaks resulting in a time variation of the spillover index.

The time varying path of the spillover index corresponds to the breakpoints identified in the previous section enabling us to judge their importance in terms of shock transmissions. The index is lower in 1985 compared to the initial period supporting the idea of a reduction in the risk of spillover contagion. It also corresponds to a decrease in contemporaneous correlation for most of the regions and reduced overall contagion risk. The further fall in 1994 is associated with decreasing mortgage rates, supply of new housing and the "buy-to-let initiative". The rise in spillover in 2003 that is not associated with a break in correlation implies that an increase in contagion is not immediate but takes time before occurring. We observe that before 1985, more than 80% the forecast error variance in regional housing market returns comes from spillovers across regions; the rest being explained by own-regional shocks. It follows a declining trend after that and hits the lower bound of around 62% in between 1994-2004 illustrating the importance of own-regional shocks. After 2005, the spillover index starts increasing and especially so after the global financial crisis. Our results thus indicate a volatile housing market systematic risk, but after the global financial crisis more towards the systemic risk. In sum, our findings of a high degree of inter-regional interdependence are in line with Tsai (2015) and Antonakakis et al. (2018). However, both papers failed to diagnose the time-varying pattern in total spillover due to structural breaks in mean, variance and correlation at unknown dates. Therefore, we believe that it is important to be careful of separating the different types of breaks to obtain a more refined picture of the dynamics of the spillover index.

Next, we focus on net and directional spillovers. The analysis of directional

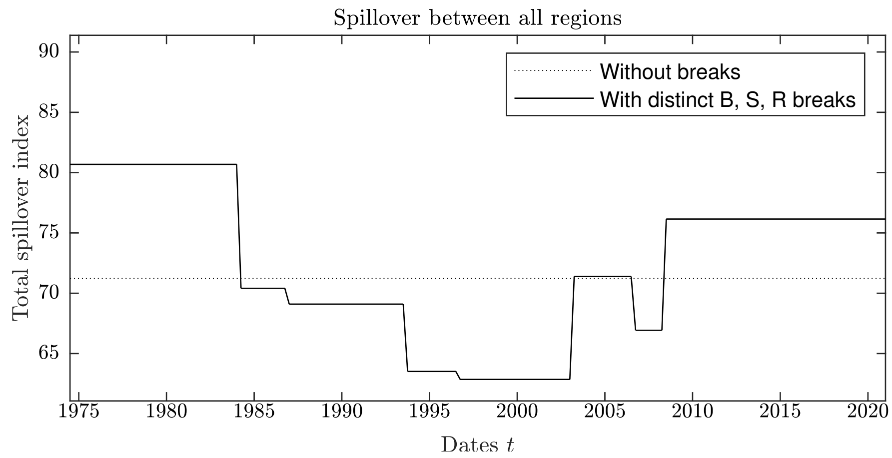

Figure 1: Total spillover index, 12-steps-ahead forecast, between 1974Q2 and 2020Q4. Either following a model without breaks, or with distinct breaks.

spillovers is particularly useful to identify the 'North-South' differences as well as the importance of 'London' in transmitting the shocks to other regions of UK. We start with 'London'; see Figures 2 and 3. The net spillover remains positive throughout the sample without breaks, but with breaks the time-variation of the spillover path becomes apparent. The same is reflected in the directional spillovers. The existence of a positive net transmission from London to the other regions for most part of the sample is evident except for the period from 1994 until 2006, where the transmission from other regions to 'London' has dominated, resulting in a net negative spillover for London. The trends in house prices in London in the initial years have tended to precede those exhibited across the rest of the country resulting in spatial differences in real house price changes, i.e., the presence of a 'ripple effect'. After 2006, we observe that the net spillover from 'London' to other regions is very close to zero implying more evenly balanced housing market spillover occurs across UK with price rises rippling out from London to other areas as buyers started to look elsewhere, i.e., a reverse North-South divide. This is in line with Holly et al. (2011) who document presence of short-run impact from other UK regions on the housing market of London. The reduced net spillover is also in line with the findings in Gray (2018) who found that London has been diverging from the rest of the country. Our analysis thus points out that more complex nature of ripple effect as it becomes time/economic event dependent.

Analysis of the ripple effect can be seen also from proximity to London. In this connection, Benito and Oswald (2000) document that a significant share of London's workforce live in the Outer Metropolitan, South East, South West, East Anglia and East Midlands. Outer Metropolitan includes places such as Luton, Watford, Sevenoaks and Woking whereas South East includes cities such as Brighton & Hove, Oxford, Winchester and Southampton. Commuter areas within about an hour of

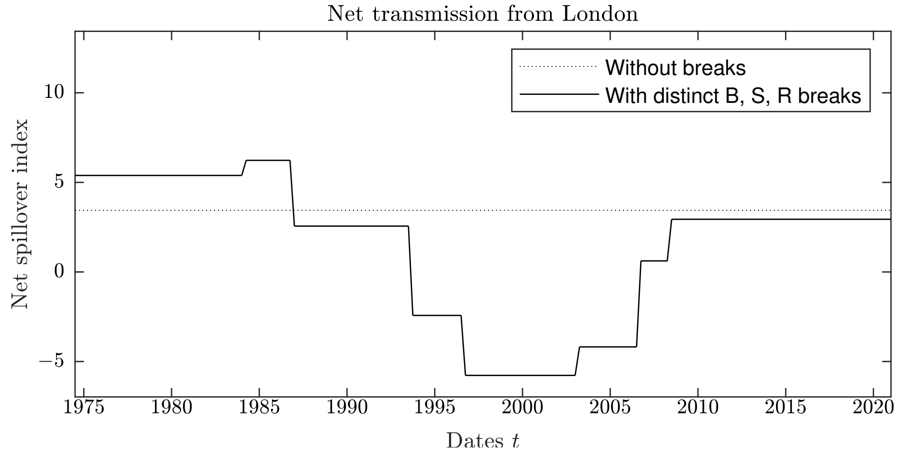

Figure 2: Net spillover, 12-steps-ahead forecast, between 1974Q2 and 2020Q4. Either following a model without breaks, or with distinct breaks.

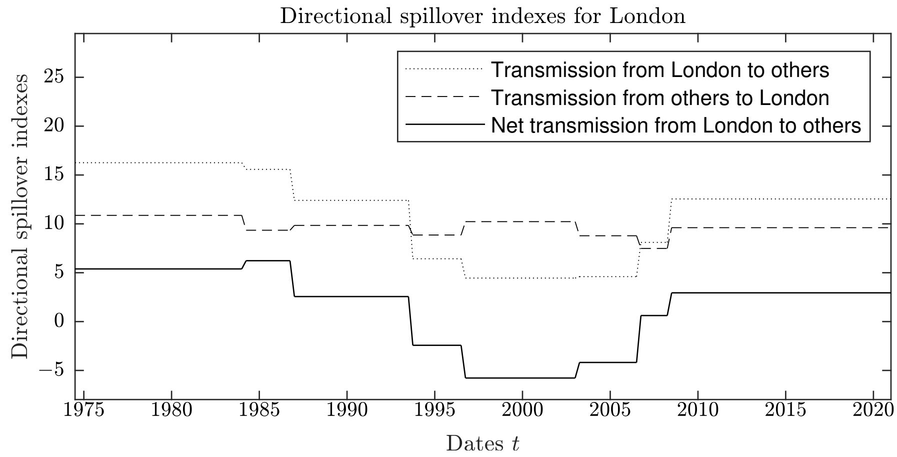

Figure 3: Directional spillovers, 12-step-ahead forecast, between 1974Q2 and 2020Q4, following a model with distinct breaks. Spillover transmitted from the region to others, spillover transmitted from other regions to the region, and net spillover transmitted from the region to others.

London have seen the biggest price growth in recent years. Therefore a shock to the London economy, for example a large number of redundancies, could be transmitted to the housing market of the neighboring regions without any internal migration. According De Goei et al. (2010), the patterns of interactions within the South East and the East of England can be characterised as a monocentric urban structure with London as the dominant node. Cameron and Muellbauer (1998) demonstrate that the East Midlands have by far the highest rate of cross-border commuting of any region and Gray (2012) shows the East Midlands is a major channel of house price diffusion until 2007. To examine this, we portray the directional spillover of the South (Figure 4) and the Midlands (Figure 5).

Several comments can be made. First, the transmission from South to other regions had outweighed transmission from others to South in the beginning of the sample. The trend reversal has started from 1996 except for the period from 2004 to 2008. Second, the net transmission for the South remains negative after 2008, thus indicating asymmetric response of the South regarding its role as a net transmitter and/or as a net receiver (Cook, 2005, Tsai, 2015). Therefore one can infer that although the housing market in South demonstrates information spillover effects affecting the overall housing market in the beginning of the sample, after the global financial crisis its role as the the leading position after London has decreased both as transmitter/receiver of spillover. This is in contrast to Tsai (2015). Third, for Midlands, the net spillover had experienced a sharp increase in 1994 and remains positive until 2006. After the global financial crisis, the spillover from others to Midlands has slightly increased compared to other parts of the sample, thus indicating more connectednees of Mildands with rest of the UK housing market. Although the workplace based GVA has grown in the East Midlands over 1997-2014, the sluggish pattern has emerged after the global financial crisis and Great Recession, and especially during 2010-2014, the growth rate stands at 14.2% below the national average (Office of National Statistics, 2016). Establishment of the West Midlands Industrial Development Association in 1984 due to increase in unemployment and economic problems of the early 1980s had led to marked improvement for inwards FDI due to its central location within the UK, with excellent national, regional and local physical communications.

Regional divergence that has been prevalent since the 1970s of a growing North-South divide in economic dynamism has continued even further for some more years. The Treasury has committed to rebalance the economy by creating a Northern Powerhouse (Martin et al., 2016) and devolving unprecedented power across the country to give local people control over decisions which drive growth, attract investment and create jobs. Initially for the North (Figure 6), the net spillover was negative, but from 1986 onward, it turns out to be positive until 2006. In 2006, the net spillover has experienced a sharp fall and becomes negative until the end of the sample: similar pattern to the one we have witnessed for Scotland (Figure 8). However, Scotland appears to be the most important receivers of inter-regional housing market return shocks from other regions after 2009. Looking at the other two devolved nations, Wales and Northern Ireland, we observe that the pattern of spillover differs from Scotland. For Wales, except for the brief period of 1994-1996 and 2006-2007, the net spillover albeit small remains positive. After the third break in the correlation matrix in 2008, the spillover from Wales to other regions of UK has dominated and turns out to be as important as London regarding transmission of shocks to other regions, a finding in sharp contrast with Antonakakis et al. (2018). An improved economic situation coupled with low cost ‘affordable’ housing in proximity to areas of relatively high employment had contributed to creating a robust housing market in Wales. Increased demand for Welsh property could also come from the Bristol direction following the abolition of Severn crossings tolls. Northern Ireland after the global financial crisis turns out to be the dominant transmitter of shocks to other regions of UK which corroborates Antonakakis et al. (2018). Since the late 1990s, Northern Ireland differs from other UK regions: in terms of social security provisions, the housing market taxation and relationship with the Republic of Ireland. Note Montagnoli and Nagayasu (2015) have shown that Northern Ireland belongs to the group of regions clearly showing convergence with the South East of the UK.

To summarize, we conclude that spillover index in UK regional house market remains volatile and therefore it is informative to accommodate for the presence of structural breaks while analysing the interlinkages of regional house prices in UK. The spillover index was more than 80% in the beginning and then following the break in mean and correlation in 1984 starts declining. The decreasing trend has further aggravated and continued until the last break in 2008. After the global financial crisis, the spillover index starts increasing but never came back to the level that was attained before 1984. Second, the transmission mechanism across the UK regions have undergone substantial change: the importance of spillover from London had decreased after 1995 until the global financial crisis and then started bouncing back. The South has acted as the net recipient after 1996 throughout the end of the sample except a brief period in between 2004-2008. Third, the influence of North including Scotland to others remains outweighed by the influence of others to these regions for most parts of sample. Fourth, both Northern Ireland and Wales turn out to be dominant transmitters of shocks to other regions of UK after the global financial crisis. Therefore the associated ripple effects have undergone changes.

5 Conclusion

Using regional data from UK, this paper explores a novel approach to analyse the spillover effect in house prices from the period 1973 to 2020. Compared to past literature, we allow for structural breaks in contemporaneous dependence as well as breaks in the dynamic transmission mechanism in a vector-autoregressive model. In our framework, the breaks are treated as endogenous and their locations are determined in a data driven way. We allow for three breaks in the conditional mean parameters, the standard deviations and the correlation coefficients of the innovations. Based on the resulting piecewise constant parameter VAR, we compute the Diebold-Yilmaz spillover index, which allows for an interpretation of the complex interplay of the changes in the different types of parameters.

We show the synchronisation of regional segments of the housing market which ultimately improves our understanding of transmission mechanism of house prices across regions of UK. UK house price bubbles materialize through inspection of the disaggregate components. In the context of the vast literature surrounding the transmission of house price shocks to surrounding areas, this paper finds mixed evidence supporting the established 'ripple effect' hypothesis. We document that the perpetual North-South divide, although present in the beginning, is becoming less evident later. London is being decoupled from the rest of the North and Midlands, however the North is becoming more integrated with Midlands and also to a lesser degree from the South. Wales is becoming more connected with Midlands and South is more or less is glued with London.

The importance of spillovers, and especially those originating in the UK regions of the London, Wales and Northern Ireland, seem to be the dominant transmitters of property returns shocks with Northern Ireland being at the highest level of the transmission process after the period of the global financial crisis. Our results show that London/South are not always as important as documented in the previous literature in transmitting shocks for other regions of UK over time. These two regions also acted as net receivers of shocks from other UK regions. Although the housing markets in the UK regions are highly interconnected, they are extremely economic event-dependent.

Our obtained results indicate readjustment of residential portfolios by the investors is necessary as the correlation structure between regions had changed due to presence of the structural break and the dates of those breaks are economic-event dependent. We contribute to the large body of literature on the North-South divide and the ripple effects in the UK housing market. Although our results share some similarities with Tsai (2015) and Antonakakis et al. (2018), we are able to unravel additional information after allowing for structural breaks while analysing the directional spillover. Therefore policymakers while formulating regulatory frameworks needs to pay attention to economic-event dependent structural breaks while paying attention to regional developments and pursue region-specific policies.

Future work could potentially apply a threshold VAR model to construct an asymmetric impulse response function to investigate declining influence of the London housing market and the North-South divide where the mortgage/income ratio or mortgage rate can potentially be used as threshold variable. On the other hand, a time-varying VAR model can also be used to understand the dynamics of regional house prices in UK or anywhere else. Further research could also focus on different types of houses where disaggregated analysis could be performed using data on sub-types of houses, for example, flats, terraced, semi-detached houses, old versus new houses using a spatial VAR model to understand the transmission of shocks emanating from one region to other. Another extension could be use of more disaggregated regional house price data available at local authority district level, where one can first perform a convergence club analysis and then depending on club formation conduct a VAR model to understand the dynamics of spillover in between members of clubs and outside club members.

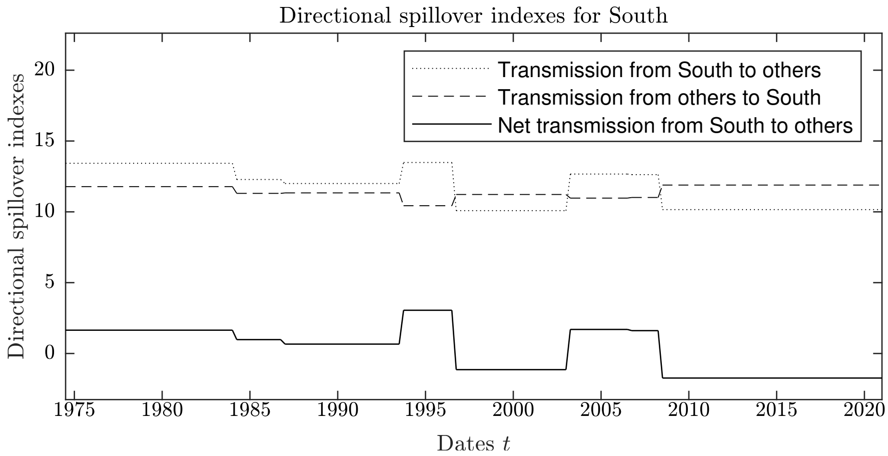

Figure 4: Directional spillovers, 12-step-ahead forecast, between 1974Q2 and 2020Q4, following a model with distinct breaks. Spillover transmitted from the region to others, spillover transmitted from other regions to the region, and net spillover transmitted from the region to others.

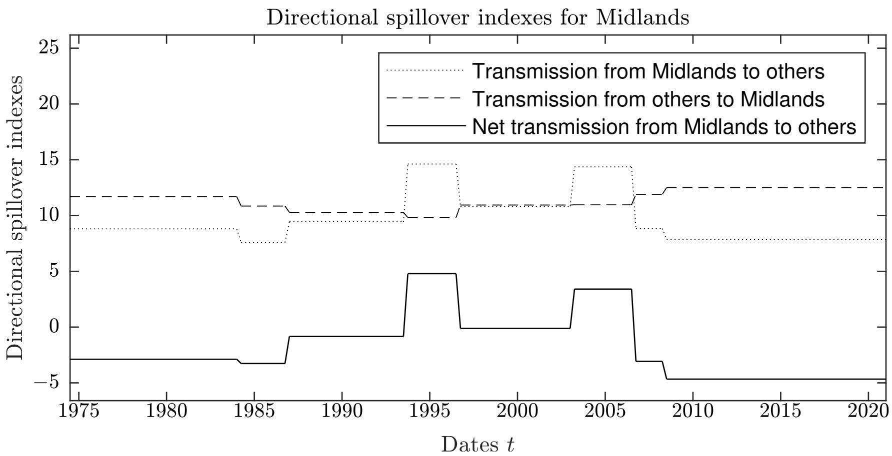

Figure 5: Directional spillovers, 12-step-ahead forecast, between 1974Q2 and 2020Q4, following a model with distinct breaks. Spillover transmitted from the region to others, spillover transmitted from other regions to the region, and net spillover transmitted from the region to others.

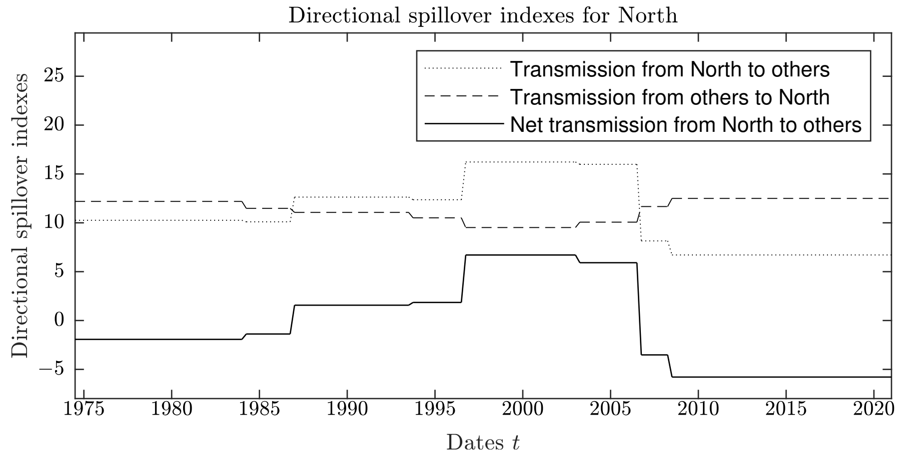

Figure 6: Directional spillovers, 12-step-ahead forecast, between 1974Q2 and 2020Q4, following a model with distinct breaks. Spillover transmitted from the region to others, spillover transmitted from other regions to the region, and net spillover transmitted from the region to others.

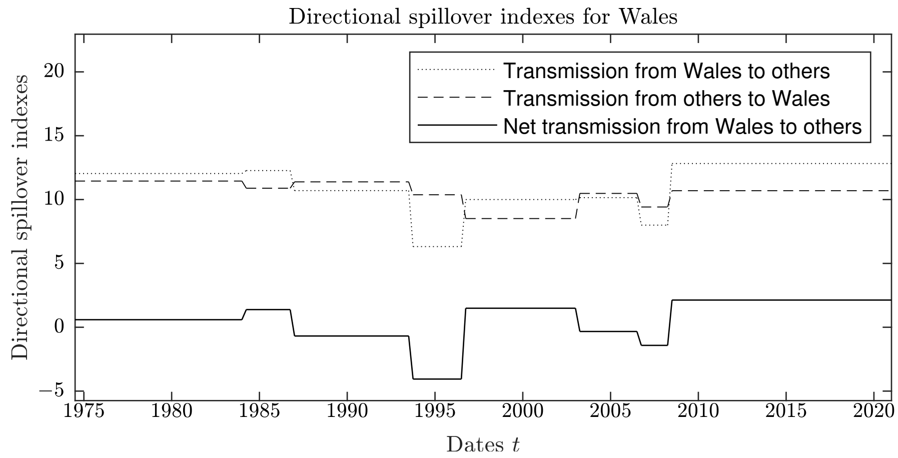

Figure 7: Directional spillovers, 12-step-ahead forecast, between 1974Q2 and 2020Q4, following a model with distinct breaks. Spillover transmitted from the region to others, spillover transmitted from other regions to the region, and net spillover transmitted from the region to others.

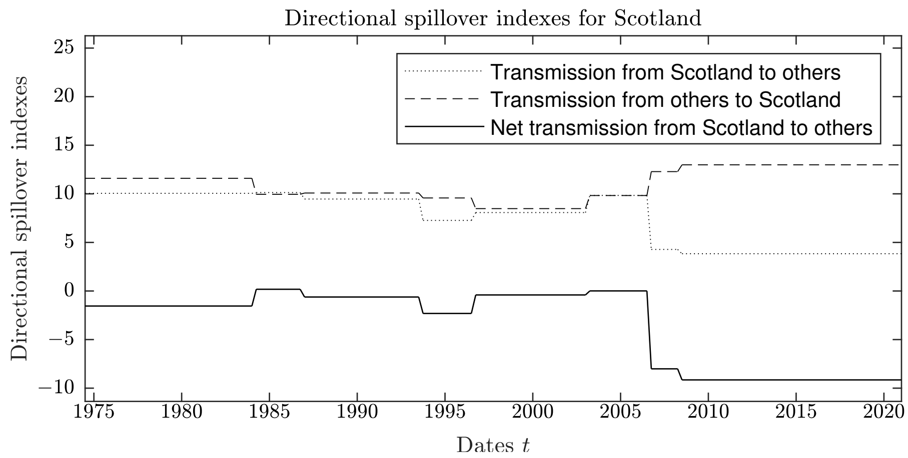

Figure 8: Directional spillovers, 12-step-ahead forecast, between 1974Q2 and 2020Q4, following a model with distinct breaks. Spillover transmitted from the region to others, spillover transmitted from other regions to the region, and net spillover transmitted from the region to others.

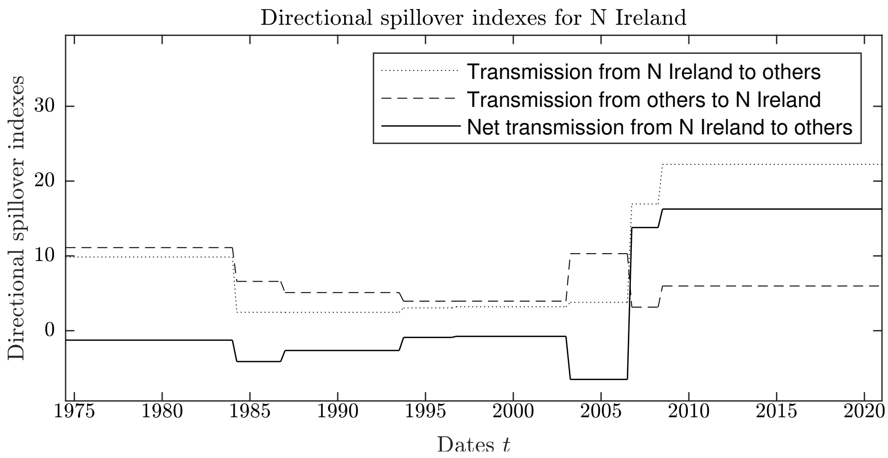

Figure 9: Directional spillovers, 12-step-ahead forecast, between 1974Q2 and 2020Q4, following a model with distinct breaks. Spillover transmitted from the region to others, spillover transmitted from other regions to the region, and net spillover transmitted from the region to others.

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