# Information Spillover across International Real Estate Investment Trusts: Evidence from an Entropy-Based Network Analysis

Qiang Ji[a,b*], Hardik A. Marfatia[c] and Rangan Gupta[d]

[a] Center for Energy and Environmental Policy research, Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China

[b] School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, China

[c] Department of Economics, Northeastern Illinois University, BBH 344G, 5500 N. St. Louis Ave., Chicago, IL 60625, USA

[d] Department of Economics, University of Pretoria, Pretoria, 0002, South Africa

**Abstract:** In this study, we unveil information spillover between international real estate markets using an entropy-based network approach for real estate investment trusts (REITs). Our novel approach is simple and yet flexible enough to accommodate the nature and extent of information spillover among several components of the global housing network. For a network of nine leading industrial economies, we unveil static and time-varying information spillover of REIT returns using total transfer entropy, pairwise net transfer entropy and directional ("From", "To") transfer entropy. Evidence suggests that the greatest pairwise transfer entropy is from the US to Australia, whereas France, the Netherlands, New Zealand and Singapore are the largest information recipients in the network. The time-varying evolution of total transfer entropy also exhibits a declining trend, supporting the decoupling hypothesis for the global housing market network. The extreme value analysis shows the changing role of US and UK housing markets.

**JEL Codes:** R30, R33, G14.

**Keywords:** REIT, Entropy transfer, Information spillover, Market integration.

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[*] Corresponding author. Center for Energy and Environmental Policy research, Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China.

Email addresses: jqwxnjq@163.com (Q. Ji), h-marfatia@neiu.edu (H.A. Marfatia), rangan.gupta@up.ac.za (R. Gupta).

## 1. Introduction

The integration of the housing markets of developed economies has posed significant challenges for macroeconomists, financial practitioners and policymakers. This is because the propagation of shocks is magnified significantly among highly integrated economies. The 2008 sub-prime mortgage crisis which triggered a global financial meltdown is clearly a case in point. The process of integration also occurs over time, leading to structural instability in the relationships which exist within the network economies. This raises the need to study the nature and extent of interconnectedness in these economies. In this paper, we measure the extent of information spillover and the degree of connectedness in global housing markets across time, using a sophisticated entropy-based network framework.

Researchers have often focused on the interconnections in the international financial markets and the impact of the U.S policies (Ayuso and Blanco, 2001; Fratzscher 2002; Marfatia, 2015). These studies find substantial international spillovers between money, bond, equity and exchange rate markets, with a dominant impact of US policies on the global financial markets. However, it is surprising that despite strong anecdotal evidence from the recent financial crisis, there are few studies which systematically explore the extent of interconnections within the returns of real estate investment trusts (REIT) in the developed markets. While the studies of André (2010) and Andrews et al. (2011) provide an overview of OECD housing markets and those of Vansteenkiste and Hiebert (2011) and Bagliano and Morana (2012) explore spillover effects among housing markets across world, there is a need to undertake a holistic system-wide approach to global REIT returns.

A network-based system-wide approach is important, because global real estate markets represented more than $1.22 trillion of equity capitalisation in July of 2016.

REITs are also very good proxies for the real estate market, providing high-frequency observable data (Akinsomi et al., 2016). Furthermore, while unsystematic risk arising out of the unique housing market dynamics can be minimised through diversification, the exposure to systematic risks depends on the degree of interdependency. Thus, it is necessary to estimate the information flows within the global REIT network both from the perspective of policymakers who try to navigate international currents and from that of international portfolio managers searching for diversification gains.

In this study, we take advantage of the connectedness framework developed by Diebold and Yilmaz (2014). In particular, we construct pairwise net transfer entropy within the network of nine industrial REIT markets, which include Australia, Canada, France, Hong Kong, the Netherlands, New Zealand, Singapore, the United Kingdom and the United States.[1] This provides us the weighted in-degree and out-degree information flow in the real estate network. We derive "From" and "To" transfer entropy to measure the information spillover among these network REIT markets. In order to take a holistic approach, a system-wide total transfer entropy is estimated. In our empirical modelling strategy, we acknowledge that the underlying structure of the global housing market has changed significantly over time, and we analyse time-varying information connections within the network. Using these apparatuses, we analyse the extent and nature of information spillover based on the extreme values of each country's REIT returns.

The results show that the largest pairwise transfer entropy in REIT returns is from the US to Australia, but from Australia to the US, there is very little information flow. The Australian REIT market is the largest recipient of information, whereas Hong

[1] These markets combined constitute 88.7% of the global REIT index, based on market capitalisation, with Australia 7.47%, Canada 2.95%, France 1.93%, Hong Kong 1.58%, the Netherlands 2.64%, New Zealand 0.12%, Singapore 1.68%, the UK 4.58%, and the US 65.19% (European Public Real Estate Association, 2016; Ntuli and Akinsomi, 2017).

Kong's real estate market receives the least amount of information from the network. Overall, Canada, Hong Kong, the UK and the US have a positive net transfer entropy, indicating that these REIT markets contribute more to the global information flow, whereas Australia, France, the Netherlands, New Zealand and Singapore exhibit negative net entropy, indicating that they are net information recipients.

The evidence from the dynamic model, however, suggests significant time variation in all the cases with respect to the extent to which a country can be and is influenced by other network partners. Results show that in the 2009–2010 period, there was significantly high information flow from the REIT returns of the US, the UK and Hong Kong to the network markets. Evidence also suggests that during the 2008 financial crisis, when house prices witnessed extreme movement, the information flow had very different network dynamics as compared to other periods. We also unveil the contrasting roles of the US and the UK REIT markets in the information network due to Brexit.

This paper makes at least four main contributions to the existing literature on both methodological and empirical fronts. First, it provides insights into the information spillover in global real estate, which includes nine developed countries producing 88% of the global REIT market turnover. The sample period ranges from 2007 to 2017, which covers the 2008 global financial crisis and geopolitical events such as Brexit. Second, the measure of transfer entropy proposed by Schreiber (2000) is introduced for the first time to analyse the integration of global housing markets. Third, using the framework of Diebold and Yilmaz (2014), we develop the idea of information connectedness by constructing a transfer entropy network and designing several useful indicators, such as total transfer entropy, pairwise net transfer entropy and directional ("From" and "To") transfer entropy. This allows us to identify the information spillover in the global real estate market network. Finally, a rolling-window approach is combined with transfer entropy for the first time to uncover the gradual evolution of information flow present in the global housing market network.

The remainder of the paper proceeds as follows. Section 2 introduces transfer entropy methodology to construct the information spillover network and various entropy measures. Section 3 presents the data source and basic statistical characteristics. Section 4 explores the static and dynamic findings on market integration and information flow among global REIT markets. The last section concludes the paper.

## 2. Methodology

Information spillover among assets is a highly researched topic in the field of financial risk management. Several methodological approaches have been applied to assess the spillover effects between asset classes and across countries, such as the Granger causality test (Hong et al., 2009; Geng et al., 2017; Jammazi et al., 2017), conditional value at risk (CoVaR) and delta conditional value at risk (ΔCoVaR) (Reboredo and Ugolini, 2015; Mensi et al., 2017; Liu et al., 2017) and the connectedness network (Diebold and Yilmaz, 2012, 2014). However, Granger causality can only provide a causal direction between variables but cannot provide further evidence on systemic risk. CoVaR and ΔCoVaR models are too complex in their coefficient estimation process. The connectedness network has recently gained popularity due to its simplicity and intuitive appeal; however, it cannot deal with the large multivariate system, because it depends on the estimation of the VAR model.

In this paper, to explore the strength and direction of the information spillover among the housing markets, we introduce the concept of transfer entropy based on mutual information flow. This approach allows us to measure information spillovers, with the advantage that it is simple and yet flexible. It is not constrained by the number of variables and can flexibly deal with asymmetric and nonlinear processes (applications of this approach in the field of finance can be found, for example in Altiparmak and Dengiz, 2009; Dimpfl and Peter, 2012; Daugherty and Jithendranathan, 2015). In this paper, we apply transfer entropy to investigate information spillover between the global housing markets.

### *2.1 Transfer entropy*

Transfer entropy was originally developed by Schreiber (2000), whose theoretical foundations were derived from Shannon entropy (Shannon, 1948). The detailed modelling process is as follows. The definition of Shannon entropy is:

$$H(X) = H(p_1, p_2, \ldots, p_k) = -\sum_k p_k \log P(x_k) \tag{1}$$

where $P(x_k)$ is the prior probability of $x_k$.

When it comes to the relationship between two different sequences, mutual information is applied. Assuming that the joint distribution of two random variables $(X,Y)$ is $p(x,y)$, the mutual information between the two random variables is measured as follows:

$$M_{xy} = \sum_{ij} p(i,j) \log \frac{p(i,j)}{p(i)p(j)}\,. \tag{2}$$

Notice that the mutual information can only provide dependency between two random variables but cannot provide the direction of information flows. In this paper, we propose transfer entropy to measure the information flow from one stationary Markov process to another. Let $X$ be a stationary Markov process of order $k$, then the probability of $X$ at time $t+1$ is conditional on the $k$ previous observations, that is, $p(x_{t+1} | x_t, \ldots, x_{t-k+1}) = p(x_{t+1} | x_t, \ldots, x_{t-k})$. The measure of information flow from process

$Y$ to $X$ can then be quantified as the deviation from the following generalised Markov property, $p(i_{t+1} | i_t^{(k)}) = p(i_{t+1} | i_t^{(k)}, j_t^{(l)})$.

Consequently, the transfer entropy measuring the information flow from process $Y$ to $X$ can be written as:

$$T_{Y \to X}(k,l) = \sum p(i_{t+1}, i_t^{(k)}, j_t^{(l)}) \log \frac{p(i_{t+1} | i_t^{(k)}, j_t^{(l)})}{p(i_{t+1} | i_t^{(k)})} \tag{3}$$

where $l$ is the order of the assumed Markov process for $Y$, and $T_{Y \to X}(k,l)$ is defined as the information flow from source Y on the next state of X which cannot be explained by the past state of X. Following the related empirical literature, we assume the presence of short memory in the housing markets and set $l=k=1$. Similarly, $T_{X \to Y}(k,l) = \sum p(j_{t+1}, j_t^{(l)}, i_t^{(k)}) \log \frac{p(j_{t+1} | j_t^{(l)}, i_t^{(k)})}{p(j_{t+1} | j_t^{(l)})}$.

***2.2 Measures of transfer entropy-based network***

From the pairwise transfer entropy presented above, we construct several measures to investigate the information spillover of the whole system. Following the connectedness framework (Diebold and Yilmaz, 2014), we first build a transfer entropy table by $T = [T_{ij}]$. As shown in Table 1, $T_{ij}$ denotes the transfer entropy from $j$ to $i$, that is $T_{ij} = T_{i \to j}$ in equation (3). To analyse information spillovers in the global housing market, we construct the following measures.

*2.2.1 Pairwise net transfer entropy*

In general, $T_{ij} \neq T_{ji}$, according to the definition of transfer entropy. So the difference between $T_{ij}$ and $T_{ji}$ can be measured as the pairwise net transfer entropy. In a network with $N$ nodes, there are $N^2 - N$ separate pairwise net transfer entropies. In the following empirical section, we construct and analyse the information flow network based on pairwise net transfer entropy. In the network, each market is set as a node, and the condition in which a directional edge from $i$ to $j$ exists in the network is $T_{ji} - T_{ij} > 0$.

Obviously, in a network, degree centrality is important to analyse the influence of the node in the system. Therefore, weighted in-degree and out-degree for a node in the network is also applied for the dynamic analysis. Weighted in-degree and out-degree are defined as:

$$D_i^{in} = \sum_j T_{ij} - T_{ji},\ \text{if and only if}\ T_{ij} - T_{ji} > 0 \tag{4}$$

$$D_i^{out} = \sum_j T_{ji} - T_{ij},\ \text{if and only if}\ T_{ji} - T_{ij} > 0\,. \tag{5}$$

*2.2.2 Transfer entropy "From" and "To"*

We use transfer entropy "From" and "To" in order to measure the total information spillover between nodes. Transfer entropy "From" is defined as the information inflow from other nodes, which is calculated by the row sum of the pairwise transfer entropy in Table 1, defining $T_{i\leftarrow\bullet} = \sum_{j=1}^{N} T_{ij},\ j \neq i$. Transfer entropy "To" is defined as the information outflow to other nodes, which is calculated by the column sum of the pairwise transfer entropy in Table 1, defining $T_{\bullet\leftarrow j} = \sum_{i=1}^{N} T_{ij}, i \neq j$.

*2.2.3. Total net transfer entropy*

The total net transfer entropy measures the net information spillover contribution of one node by the difference between transfer entropy "To" and "From", defined as $T_i = T_{\bullet\leftarrow i} - T_{i\leftarrow\bullet}$.

*2.2.4. Total transfer entropy for the system*

The integration or systemic risk of a system is measured by the total transfer entropy for the system. This is defined as the average transfer entropy of the sum of transfer entropy "From" or "To", defined as $T_{total} = \frac{1}{N}\sum_{i,j=1}^{N} T_{ij}, i \neq j$.

**Table 1. Transfer entropy matrix**

| | $x_1$ | $x_2$ | $\cdots$ | $x_N$ | From others |
|---|---|---|---|---|---|
| $x_1$ | $T_{11}$ | $T_{12}$ | $\cdots$ | $T_{1N}$ | $\sum_{j=1}^{N} T_{1j}, j \neq 1$ |
| $x_2$ | $T_{21}$ | $T_{22}$ | $\cdots$ | $T_{2N}$ | $\sum_{j=1}^{N} T_{2j}, j \neq 2$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\ddots$ | $\vdots$ | $\vdots$ |
| $x_N$ | $T_{N1}$ | $T_{N2}$ | $\cdots$ | $T_{NN}$ | $\sum_{j=1}^{N} T_{Nj}, j \neq N$ |
| To others | $\sum_{i=1}^{N} T_{i1}, i \neq 1$ | $\sum_{i=1}^{N} T_{i2}, i \neq 2$ | $\cdots$ | $\sum_{i=1}^{N} T_{iN}, i \neq N$ | $\frac{1}{N}\sum_{i,j=1}^{N} T_{ij}, i \neq j$ |

## 3. Data and sample description

In this study, we explore the information network of the nine major REIT markets.[2] These markets constitute 88.7% of the global REIT index, based on market capitalisation, with Australia 7.47%, Canada 2.95%, France 1.93%, Hong Kong 1.58%, the Netherlands 2.64%, New Zealand 0.12%, Singapore 1.68%, the UK 4.58% and the US 65.19% (European Public Real Estate Association, 2016; Ntuli and Akinsomi, 2017). These markets are considered mature based on nine different criteria, which include capital flows, financial reporting, corporate governance, risk management, regulatory environment, cross-border issues, transaction activity, financing and property specifics (EY Global perspectives: 2016 REIT report). The sample period ranges from

[2] The REIT prices are transformed into returns by taking first-differences of the natural logarithms of the data.

1 February 2007 to 24 August 2017, with 2,757 observations for nine REIT markets. As mentioned, these markets constitute more than 88% of the global REIT market. This makes the present study one of the most comprehensive analyses of information spillovers. Table 2 presents the summary statistics for REIT returns. The evidence from Panel A shows that the average REIT return is negative in all cases except that of Hong Kong. The negative average returns are possibly driven by the large synchronous declines in housing markets due to the global financial crisis. This indirectly supports the main idea of the paper, that is the need to analyse the degree and extent of information interconnectedness between these markets.

Among the developed markets, the United Kingdom, the Netherlands and Australia registered the largest REIT declines. Although the average US REIT return is almost zero (-0.001), it witnessed the largest volatility, with a standard deviation of 2.245. The REIT returns of all the markets are skewed and exhibit significant leptokurtosis, showing a non-normal distribution. This can also be seen by the significant statistics from the Jarque-Bera test.

Panel B of Table 2 presents the unconditional correlations among the countries' REIT returns. The results show that the pairwise correlations are statistically significant at the 1% level (the correlation between the US and Hong Kong is significant at the 5% level). This indicates that the REITs in different developed countries tend to move together, possibly sharing common information and responding similarly to external shocks. Specifically, the correlations between the US and other countries and between Hong Kong and other countries are relatively smaller than other correlations. This means that the real estate markets in the US and Hong Kong are relatively independent of other markets. In addition, the real estate markets in some European countries are found to have strong correlations. For example, the pairwise correlation between the

UK, France and the Netherlands is larger than 0.7. To some extent, this could be due to the influence of geographical location on the co-movement of REIT returns.

**Table 2. Summary statistics for countries' REIT returns**

| **Panel A: Summary** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Variables | Mean | Max. | Min | Std. Dev | Skewness | Kurtosis | Jarque-Bera |
| **AU** | -0.022 | 10.502 | -18.474 | 1.862 | -1.038 | 14.109 | 14667.25** |
| **CA** | -0.001 | 8.510 | -11.831 | 1.307 | -0.729 | 13.582 | 13102.74** |
| **FR** | -0.003 | 9.550 | -10.358 | 1.768 | -0.085 | 6.013 | 1045.76** |
| **HK** | 0.037 | 10.115 | -13.294 | 1.176 | -0.603 | 17.388 | 23939.61** |
| **NL** | -0.028 | 8.625 | -8.267 | 1.710 | -0.209 | 6.287 | 1260.463** |
| **NZ** | -0.003 | 7.962 | -9.393 | 1.201 | -0.548 | 8.748 | 3931.95** |
| **SG** | -0.002 | 20.564 | -17.750 | 1.392 | 0.387 | 36.021 | 125286.6** |
| **UK** | -0.035 | 11.704 | -24.273 | 1.979 | -0.993 | 15.850 | 19414.89** |
| **US** | -0.001 | 17.124 | -21.945 | 2.245 | -0.155 | 17.541 | 24291.11** |

| **Panel B: Unconditional correlations** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **AU** | **CA** | **FR** | **HK** | **NL** | **NZ** | **SG** | **UK** | **US** |
| **AU** | 1.000 | | | | | | | | |
| **CA** | 0.433** | 1.000 | | | | | | | |
| **FR** | 0.473** | 0.580** | 1.000 | | | | | | |
| **HK** | 0.338** | 0.245** | 0.224** | 1.000 | | | | | |
| **NL** | 0.465** | 0.576** | 0.869** | 0.217** | 1.000 | | | | |
| **NZ** | 0.541** | 0.462** | 0.457** | 0.252** | 0.465** | 1.000 | | | |
| **SG** | 0.538** | 0.416** | 0.440** | 0.399** | 0.432** | 0.439** | 1.000 | | |
| **UK** | 0.433** | 0.532** | 0.755** | 0.209** | 0.728** | 0.433** | 0.402** | 1.000 | |
| **US** | 0.101** | 0.479** | 0.329** | 0.045* | 0.329** | 0.131** | 0.098** | 0.304** | 1.000 |

Note: * and ** denote the 5% and 1% significance levels, respectively.

## 4. Empirical analysis

In this section, we analyse the information spillover among countries' REIT returns from static and dynamic perspectives. Different measures of transfer entropy networks have been analysed to verify the structure, direction and strength of the global real estate network.

### *4.1 Static analysis for full sample*

We first study transfer entropy among countries' REIT returns for the full sample period using different measures, namely pairwise net transfer entropy, transfer entropy

“To” and “From” the network nodes and total transfer entropy for the system. Evidence from pairwise transfer entropy (Table 3) suggests that the largest pairwise transfer entropy is from the US to Australia (0.139). In contrast, the pairwise transfer entropy from Australia to the US is small (0.049). The difference between the two instances of pairwise transfer entropy means that the net transfer entropy from the US to Australia is 0.09.

In Table 3, the row sum of the pairwise transfer entropy indicates the total transfer entropy from other nodes to each of the nine REIT returns. In this sense, it measures the information spillover between markets. Results show that the largest row sum of the total transfer entropy “From” is for Australia, and the smallest total transfer entropy “From” is for Hong Kong. This means the amount of information that the Australian real estate market receives from other REIT markets is the greatest among the nine markets, while Hong Kong receives the least amount of information from the other markets. The net information receiver feature of the Australian market corroborates the paradox of the relatively stable Australian housing system despite deepening housing affordability problems (Burke and Hulse, 2010; Andrews et al., 2011).

The column sum of the pairwise transfer entropy also indicates the total transfer entropy from each of the nine REIT returns to other nodes. It measures the information contribution of one market to other markets’ dynamics. The largest total transfer entropy “To” is the US REIT market (0.647), while the smallest is the Hong Kong REIT market (0.156). This indicates that real estate market information in Hong Kong is relatively independent of other markets, consistent with the correlation results found in Table 2.

The net transfer entropy for each country, as measured by the difference between total transfer entropy “To” and “From”, are negative in the case of Australia, France, the Netherlands, New Zealand and Singapore. This implies that these countries are information recipients in the REIT global network. In contrast, Canada, Hong Kong, the UK and the US have positive net transfer entropy, indicating that these REIT markets contribute more to the global information flow. The US has the largest net transfer entropy, highlighting the leading role of the US real estate market, while Australia has the smallest net transfer entropy, highlighting the relatively stable and insulated Australian housing market. Evidence of negative net transfer entropy (net receiver of information) in the case of the housing market of Australia and New Zealand can be explained by the unique combination of pre-existing institutional practices, market conditions and government policies which sheltered these markets from rest of the network (Murphy, 2011; Gurran and Phibbs, 2013).

These results are intuitively appealing. In the unfolding of the recent financial crisis, the US housing market developments did indeed play a leading role in driving the global markets. One of the rationales for the extent to which the housing markets contribute to the global information flows could be recent developments in unconventional monetary policy. Anecdotal evidence shows that several central banks of the industrial economies have recently undertaken policy steps, led by the US and the UK, which were largely synchronous in nature. This, then, is reflected in the nature and extent of the information flow from and to the network economies, as revealed by the findings of our newly developed entropy-based network.

**Table 3. Pairwise transfer entropy over the full sample**

| | AU | CA | FR | HK | NL | NZ | SG | UK | US | From |
|---|---|---|---|---|---|---|---|---|---|---|
| **AU** | 0 | 0.067 | 0.054 | 0.027 | 0.052 | 0.026 | 0.052 | 0.074 | 0.139 | 0.491 |
| **CA** | 0.031 | 0 | 0.004 | 0.020 | 0.011 | 0.021 | 0.044 | 0.023 | 0.057 | 0.210 |
| **FR** | 0.044 | 0.025 | 0 | 0.019 | 0.034 | 0.017 | 0.009 | 0.041 | 0.089 | 0.277 |
| **HK** | 0.012 | 0.008 | 0.008 | 0 | 0.002 | 0.018 | 0.026 | 0.013 | 0.047 | 0.132 |
| **NL** | 0.039 | 0.020 | 0.017 | 0.018 | 0 | 0.013 | 0.027 | 0.036 | 0.087 | 0.257 |
| **NZ** | 0.024 | 0.014 | 0.020 | 0.011 | 0.030 | 0 | 0.033 | 0.040 | 0.046 | 0.218 |
| **SG** | 0.029 | 0.044 | 0.035 | 0.029 | 0.042 | 0.023 | 0 | 0.052 | 0.100 | 0.356 |
| **UK** | 0.038 | 0.038 | 0.012 | 0.018 | 0.013 | 0.045 | 0.055 | 0 | 0.083 | 0.301 |
| **US** | 0.049 | 0.031 | 0.052 | 0.015 | 0.034 | 0.042 | 0.053 | 0.049 | 0 | 0.325 |
| **To** | 0.266 | 0.247 | 0.202 | 0.156 | 0.217 | 0.206 | 0.300 | 0.326 | 0.647 | |
| **NET** | -0.225 | 0.037 | -0.075 | 0.024 | -0.040 | -0.012 | -0.056 | 0.025 | 0.322 | 0.285 |

To produce a visual representation, we construct an information flow network based on the pairwise net transfer entropy. This is presented in Figure 1. If and only if the pairwise net transfer entropy from country i to country j is larger than zero, then there exists an arrow edge from i to j. In the figure, node colour represents the structure hierarchy of the information flow network, node size indicates the market power of the information spillover and edge size indicates the magnitude of the pairwise net transfer entropy. A larger sized node means that this node can provide information to many other nodes, that is, there are more arrows originating from this node.

It can be seen in Figure 1 that the nodes can be divided into six hierarchies. The US ranks first in the hierarchy, as it has an arrow originating only from it (the out-degree of the US is eight). It means that there is information spillover from the US to all the other countries. Hong Kong, which has only one arrow pointing to it (US→HK), ranks second in the hierarchy. Canada ranks third, with information flowing from the US and Hong Kong. The Netherlands and New Zealand rank fourth in the hierarchy with an out-degree at four. Subsequently, Singapore, the United Kingdom and

France rank fifth in the hierarchy, while Australia ranks last, only playing the role of an information recipient.

Several channels support the global REIT market network depicted in Figure 1. The information flow in the REIT network could be channelled through the US monetary policy and macroeconomic surprises (Marfatia et al., 2017). The international REIT market network can also be argued to be tied to the country’s exchange rate regime, its degree of real economic and financial integration (Xu and Yang, 2011) and its market penetration (Marfatia et al., 2017). The other channel through which the international REIT markets are connected is global trade. A slowdown in an economy, for example, will affect the volume of trade, which, in turn, leads to greater information spillover in the REIT markets of that country’s major trading partners.

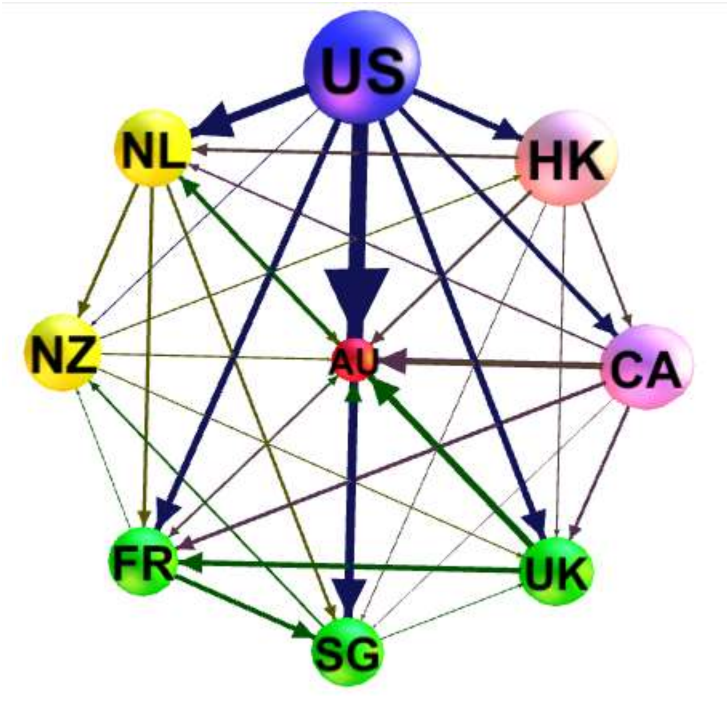


**Figure 1. Information flow network based on pairwise net transfer entropy over the full sample**

### *4.2 Dynamic analysis for the full sample*

The static analysis in the above section presents the time-invariant characteristics of information flow among the real estate markets. However, it is possible to argue that the global economy has witnessed large structural changes, and this alters the extent and degree of information spillover in the global housing markets. The merit of this argument can be found in the evidence of time-varying integration of the financial markets (Bekaert and Harvey, 2003; Jong and Roon, 2005; Panchenko and Wu, 2009). To account for structural changes and the dynamic nature of the global housing network, we extend the analysis using a rolling-window approach. We set the length of the rolling window to 250 days, which approximately corresponds to a one-year trading period. This allows us to obtain 2,507 dynamic transfer-entropy-based real estate networks.

Recall that the total transfer entropy is a measure of information spillover for the whole network, thus reflecting the extent of network integration. Figure 2 presents the time-varying dynamic evolution of the total transfer entropy. Evidence suggests that the total transfer entropy has declined overall in the 2008–2017 period. But notice that even though the total information spillover based on the transfer entropy network has declined, there is significant variation in this pattern across time. Thus, in the 2010–2015 period, the global housing markets decoupled from each other (there is less network information spillover), whereas the decoupling effects are found to have been declining post-2015.

One of the explanations of the decoupling effects, as revealed by a declining total information spillover within the network, is the sequencing of global central banks' policy actions, particularly the US Federal Reserve. Global investors had reasonable foresight that the unconventional monetary policy actions of leading central banks, including the US Federal Reserve, would continue for the foreseeable future in the post-crisis period. In this sense, while monetary policy conventionally held significant information for the REIT markets, a rather clear forecast of policy stance meant that the flow of information in the global REIT network declined. This argument is supported by the reverse trend of information flow which we find in Figure 2 ever since the Federal Reserve marked a milestone in 2015 by ending seven years of holding its key interest near zero. The lift-off phenomena have made investors once again eye policy actions, and we find an increase in information spillover in Figure 2.

Most of the existing literature on decoupling effects is largely centred around business cycle movements between developed and emerging markets. For example, Kose et al. (2012) found that during 1985–2008, there was some convergence of business cycle fluctuations among industrial economies and emerging markets. However, the study found that there was a concomitant decline in the relative importance of the global factor. In the context of global housing markets, we provide new insights into this literature. Even while house prices in the 1971–2011 period were synchronised across industrial countries (Hirata et al., 2012), evidence from the present study suggests that there was a declining trend in the total transfer entropy in the global real estate market network in the 2010–2015 period, and consequently, the markets are decoupled in this sense.

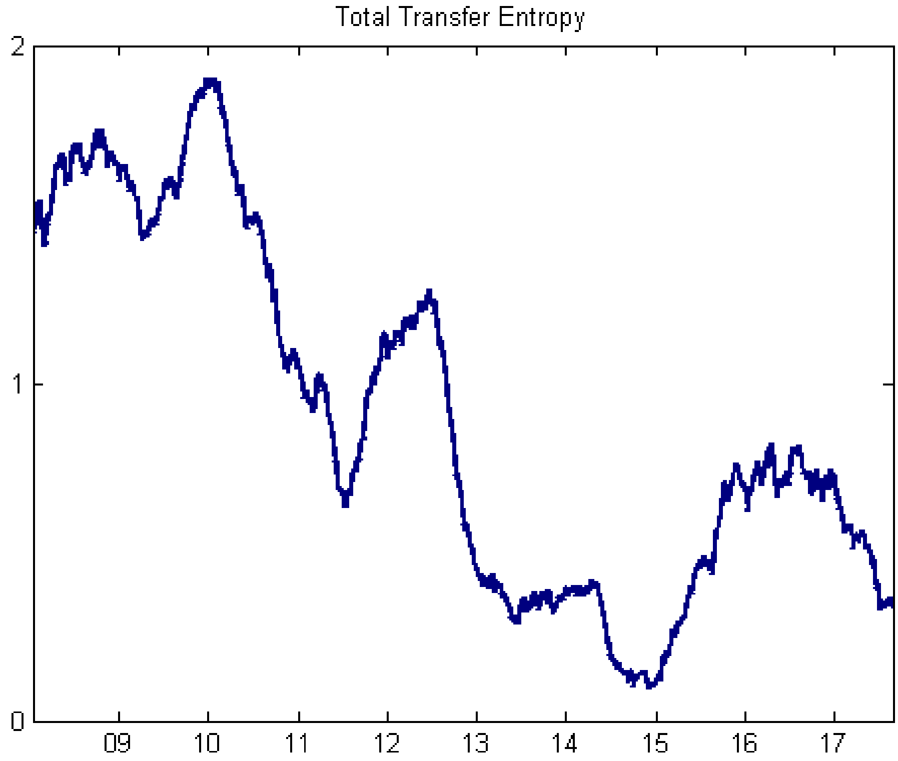


**Figure 2. Dynamic total information spillover based on transfer entropy network**

Figure 3 depicts the weighted out-degree (red line) and in-degree (blue line) for each country in the network, under this approach. The evidence clearly suggests significant time variation in the extent to which each country can influence (out-degree, red line) and can be influenced by (in-degree, blue line) other network partners. For example, the 2009–2010 period witnessed a significantly high information flow from the US, the UK and Hong Kong to the network REIT markets. In the same period, France, New Zealand and Singapore were significant information recipients (in-degree, blue line, rises sharply in the markets in that period).

These results correspond to the summary statistics of the weighted in-degree and out-degree for each country, presented in Table 4. The US REIT market has the highest weighted average out-degree (0.382) followed by Hong Kong (0.324), whereas France witnessed the highest weighted average in-degree (0.36) followed by the Netherlands

(0.297). This highlights the nature of the dependence of European housing markets on US conditions.

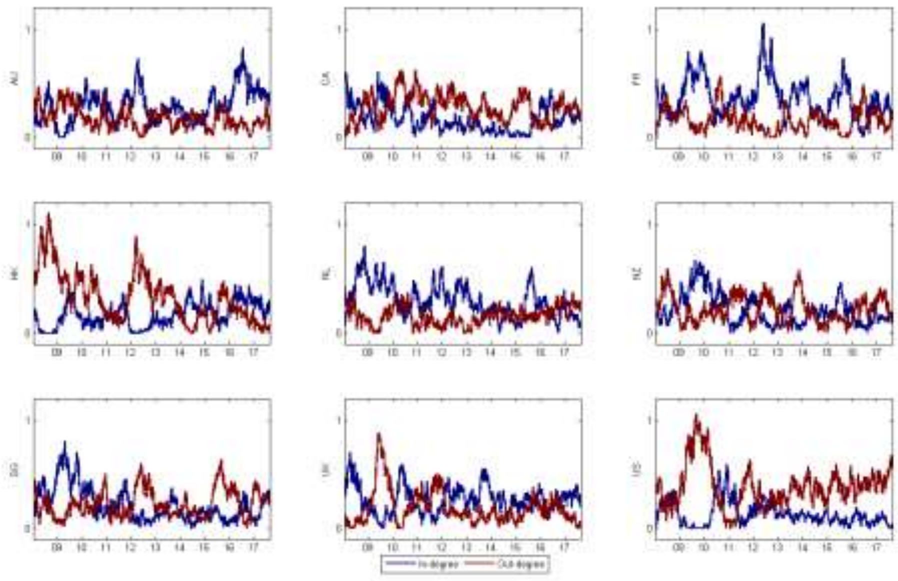

**Figure 3. Evolution of weighted in-degree and out-degree for each country in the directional transfer entropy-based network**

**Table 4. Summary statistics of weighted in-degree and out-degree for each country in the entropy-based network**

| Country degree | Mean | Max | Min | Std. Dev |
|---|---|---|---|---|
| **AU (In)** | 0.286 | 0.826 | 0.000 | 0.149 |
| **AU (Out)** | 0.171 | 0.473 | 0.000 | 0.095 |
| **CA (In)** | 0.170 | 0.607 | 0.000 | 0.120 |
| **CA (Out)** | 0.277 | 0.623 | 3.890E-04 | 0.125 |
| **FR (In)** | 0.360 | 1.063 | 5.763E-03 | 0.179 |
| **FR (Out)** | 0.154 | 0.574 | 0.000 | 0.102 |
| **HK (In)** | 0.165 | 0.495 | 0.000 | 0.110 |
| **HK (Out)** | 0.324 | 1.108 | 0.000 | 0.226 |
| **NL (In)** | 0.297 | 0.804 | 0.000 | 0.150 |
| **NL (Out)** | 0.153 | 0.427 | 0.000 | 0.083 |
| **NZ (In)** | 0.208 | 0.672 | 0.000 | 0.136 |
| **NZ (Out)** | 0.220 | 0.595 | 0.000 | 0.121 |
| **SG (In)** | 0.213 | 0.808 | 1.456E-03 | 0.154 |
| **SG (Out)** | 0.224 | 0.638 | 2.797E-03 | 0.125 |
| **UK (In)** | 0.263 | 0.702 | 0.000 | 0.121 |
| **UK (Out)** | 0.186 | 0.891 | 0.000 | 0.157 |
| **US (In)** | 0.129 | 0.593 | 0.000 | 0.105 |
| **US (Out)** | 0.382 | 1.062 | 1.626E-03 | 0.196 |

We also explore the dynamic pairwise transfer entropy ("From" and "To") for each country. Figure 4 shows that the "From" and the "To" transfer entropy closely overlap each other in each case. Moreover, the overall trend, though found to exhibit large time variations, is declining in the 2009–2017 period. This corroborates the evidence found in Figure 2 of an overall decline in dynamic total information spillover, based on the transfer entropy network. Table 5 provides summary statistics for dynamic transfer entropy ("From" and "To"). Results show that the mean "From" entropy is relatively high in the REIT markets of Australia (1.064), France (1.116) and the Netherlands (1.064), whereas the highest mean "To" entropy occurs in the case of the US (1.106), followed by Australia (0.949) and the UK (0.915). The high "From" and "To" entropies in the case of Australia suggest that when one accounts for structural changes, the Australian real estate market plays a much larger role in the global housing market network information flows. This highlights the need to model time variations in exploring information spillovers.

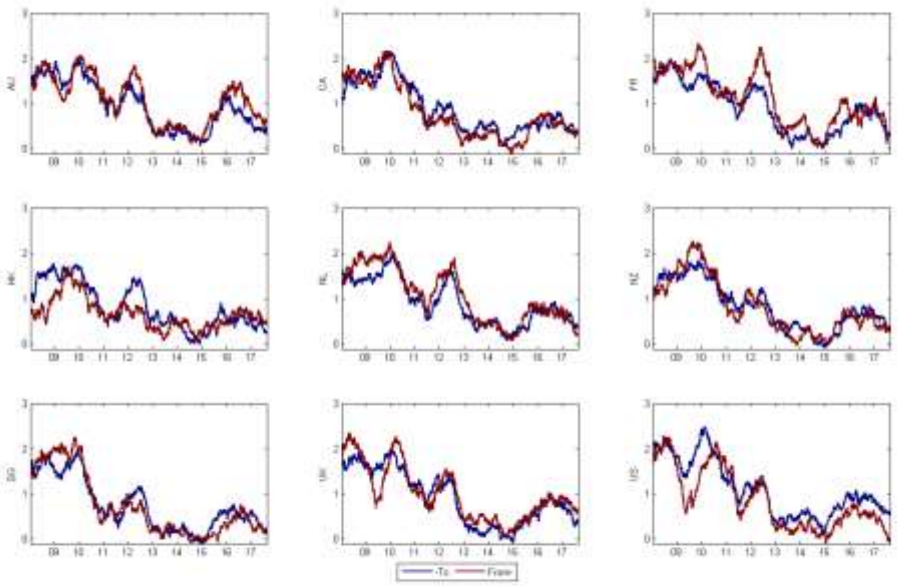

**Figure 4. Dynamic pairwise transfer entropy ("From" and "To") for each country**

**Table 5. Summary statistics for dynamic transfer entropy (“From” and “To”) results**

| Transfer entropy | Mean | Max | Min | Std. Dev |
|---|---|---|---|---|
| **AU (To)** | 0.949 | 1.955 | 0.130 | 0.531 |
| **AU (From)** | 1.064 | 2.084 | 0.070 | 0.528 |
| **CA (To)** | 0.895 | 2.162 | 0.063 | 0.547 |
| **CA (From)** | 0.787 | 2.161 | -0.111 | 0.598 |
| **FR (To)** | 0.910 | 2.003 | 0.014 | 0.540 |
| **FR (From)** | 1.116 | 2.336 | -0.001 | 0.594 |
| **HK (To)** | 0.825 | 1.770 | -0.001 | 0.498 |
| **HK (From)** | 0.666 | 1.704 | 0.076 | 0.330 |
| **NL (To)** | 0.920 | 2.007 | 0.088 | 0.491 |
| **NL (From)** | 1.064 | 2.246 | 0.079 | 0.584 |
| **NZ (To)** | 0.837 | 1.858 | -0.056 | 0.512 |
| **NZ (From)** | 0.825 | 2.272 | -0.028 | 0.595 |
| **SG (To)** | 0.744 | 1.986 | -0.120 | 0.566 |
| **SG (From)** | 0.733 | 2.258 | -0.073 | 0.688 |
| **UK (To)** | 0.915 | 2.035 | -0.057 | 0.596 |
| **UK (From)** | 0.992 | 2.357 | 0.047 | 0.592 |
| **US (To)** | 1.106 | 2.492 | 0.093 | 0.607 |
| **US (From)** | 0.853 | 2.296 | -0.070 | 0.646 |

Figure 5 presents the dynamic net transfer entropy for REITs of each country, and the summary statistics for the same can be found in Table 6. We find that while the net transfer entropy in the case of the US and Hong Kong real estate markets has remained relatively constant in the post-2011 period, there is significant time variation in all other countries, particularly Canada, France and Singapore. The results in Table 6 show that the net transfer entropy, on average, is positive for five out of nine countries. Thus, these REIT markets (Canada, Hong Kong, New Zealand, Singapore and the US) contributed to the global flow of information in the housing market network.

Results also show that the REIT markets of New Zealand and Singapore exhibited net negative transfer entropy in the static case but positive mean net transfer entropy under the dynamic scenario. In contrast, the UK market switched signs from positive in the static case to negative under the dynamic case. Thus, ignoring the structural dynamics, the UK real estate market contributes significantly in the global information

REIT market flow, but after modelling time variation, it becomes a net receiver of information, on average. This also highlights the importance of using the dynamic approach to information flow between global housing market networks.

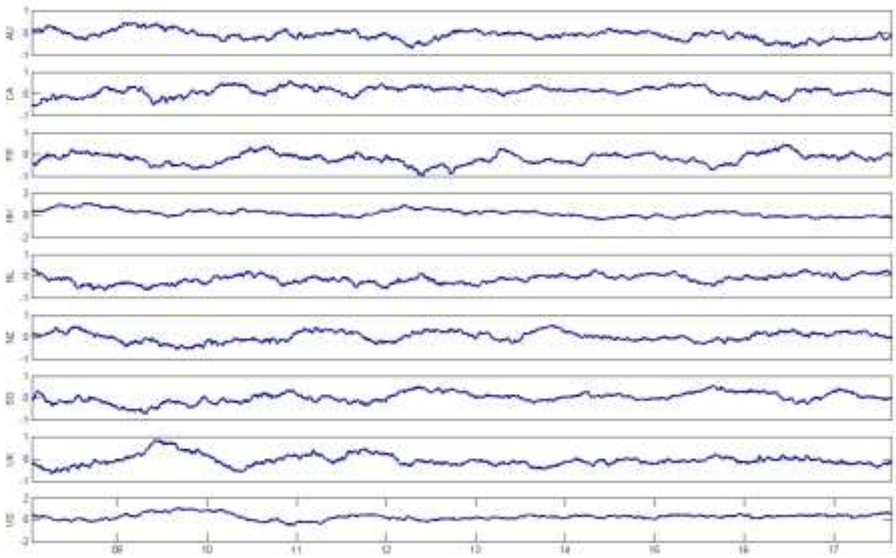

**Figure 5. Dynamic net transfer entropy for each country**

**Table 6. Summary statistics for dynamic net transfer entropy results**

| Net transfer entropy | Mean | Max. | Min | Std. Dev | Proportion (%)[a] |
|---|---|---|---|---|---|
| **AU** | -0.115 | 0.444 | -0.692 | 0.215 | 28.321 |
| **CA** | 0.107 | 0.589 | -0.580 | 0.207 | 72.158 |
| **FR** | -0.206 | 0.457 | -0.974 | 0.251 | 19.505 |
| **HK** | 0.159 | 1.108 | -0.413 | 0.313 | 62.505 |
| **NL** | -0.144 | 0.344 | -0.694 | 0.200 | 26.286 |
| **NZ** | 0.012 | 0.509 | -0.550 | 0.222 | 51.576 |
| **SG** | 0.011 | 0.571 | -0.762 | 0.237 | 53.171 |
| **UK** | -0.077 | 0.834 | -0.695 | 0.252 | 27.802 |
| **US** | 0.253 | 1.062 | -0.521 | 0.276 | 84.005 |
| **Total** | 0.900 | 1.906 | 0.094 | 0.525 | |

Note: [a] Proportion denotes the share of net transfer entropy whose values are larger than 0 in the total rolling samples.

### *4.3 Financial crisis: extreme value analysis*

In the case of real estate markets, one can argue that the unfolding of the recent financial crisis can lead to different information spillover between countries. In order to obtain further insights into the nature of relationships in global real estate markets, we track the extreme values for each country's REIT returns. From Table 7, we see that the maximum and minimum returns over the sample period for most countries happened during the 2008 global financial crisis, except for the United Kingdom, whose minimum returns happened on 24 June 2016, when Britain announced the referendum outcome for Brexit. We use our newly developed approach to further scrutinise information spillover in the global real estate network on these two dates.

**Table 7. Dates for countries' extreme REIT returns**

| Country | Maximum | Date | Net entropy | Total entropy | Minimum | Date | Net entropy | Total entropy |
|---|---|---|---|---|---|---|---|---|
| **AU** | 10.502 | 2008/10/13 | -0.162 | 1.704 | -18.474 | 2008/10/24 | -0.102 | 1.730 |
| **CA** | 8.510 | 2008/11/28 | 0.227 | 1.667 | -11.831 | 2008/11/20 | 0.312 | 1.662 |
| **FR** | 9.550 | 2009/1/26 | -0.087 | 1.639 | -10.358 | 2008/10/6 | 0.037 | 1.729 |
| **HK** | 10.115 | 2008/11/25 | 0.635 | 1.669 | -13.294 | 2008/10/10 | 0.853 | 1.696 |
| **NL** | 8.625 | 2008/10/29 | -0.510 | 1.695 | -8.267 | 2008/10/22 | -0.497 | 1.753 |
| **NZ** | 7.962 | 2008/10/29 | 0.041 | 1.695 | -9.393 | 2008/10/24 | 0.031 | 1.730 |
| **SG** | 20.564 | 2008/12/29 | -0.436 | 1.632 | -17.750 | 2008/12/30 | -0.454 | 1.620 |
| **UK** | 11.704 | 2009/4/2 | 0.192 | 1.425 | -24.273 | 2016/6/24 | 0.028 | 0.697 |
| **US** | 17.124 | 2008/11/24 | 0.049 | 1.661 | -21.945 | 2008/12/1 | -0.018 | 1.685 |

The evidence in Table 7 suggests that on 22 October 2008, the US did play a leading role in transmitting information (the "To" entropy is 2.064); it was also receiving significant information from the network (the "From" entropy is 2.008). This is possibly explained by the largely integrated nature of the US economy in the global network. However, this also meant that the net transfer entropy of the US in the network was 0.056. It is also interesting to find that while the UK was an overall information transmitter in the network (net transfer entropy is positive in Table 3), it was a net receiver of information on 22 October 2008 (the net transfer entropy is -0.201 in Table 8). The role of Australia, France, the Netherlands and Singapore as net information receivers was unchanged during the crisis period. This is also reflected in the information flow network depicted in Figure 6.

**Table 8. Pairwise transfer entropy on 22 October 2008**

| | AU | CA | FR | HK | NL | NZ | SG | UK | US | From |
|---|---|---|---|---|---|---|---|---|---|---|
| **AU** | 0 | 0.204 | 0.276 | 0.201 | 0.178 | 0.236 | 0.290 | 0.156 | 0.346 | 1.888 |
| **CA** | 0.217 | 0 | 0.270 | 0.171 | 0.184 | 0.130 | 0.230 | 0.213 | 0.202 | 1.618 |
| **FR** | 0.234 | 0.245 | 0 | 0.200 | 0.193 | 0.247 | 0.212 | 0.304 | 0.319 | 1.954 |
| **HK** | 0.166 | 0.118 | 0.140 | 0 | 0.016 | 0.058 | 0.062 | 0.246 | 0.165 | 0.971 |
| **NL** | 0.276 | 0.306 | 0.121 | 0.181 | 0 | 0.287 | 0.275 | 0.194 | 0.295 | 1.935 |
| **NZ** | 0.195 | 0.183 | 0.170 | 0.160 | 0.115 | 0 | 0.212 | 0.213 | 0.278 | 1.524 |
| **SG** | 0.254 | 0.242 | 0.301 | 0.195 | 0.266 | 0.171 | 0 | 0.240 | 0.259 | 1.927 |
| **UK** | 0.216 | 0.183 | 0.303 | 0.283 | 0.279 | 0.223 | 0.261 | 0 | 0.202 | 1.950 |
| **US** | 0.212 | 0.281 | 0.344 | 0.285 | 0.207 | 0.209 | 0.288 | 0.183 | 0 | 2.008 |
| **To** | 1.770 | 1.761 | 1.925 | 1.675 | 1.438 | 1.562 | 1.831 | 1.749 | 2.064 | |
| **NET** | -0.117 | 0.143 | -0.028 | 0.703 | -0.497 | 0.038 | -0.097 | -0.201 | 0.056 | 1.753 |

The information flow network on 22 October 2008 shows that in contrast to Hong Kong's ranking second in the hierarchy (US→HK) for the full sample, it ranked first in the hierarchy on that date. The US, on the other hand, ranked first in the full sample, but on this date, it ranked third in the hierarchy, whereas in Figure 1 (full sample) and Figure 6 (22 October 2008), the roles of Australia, France and the UK in the information network were found to be similar.

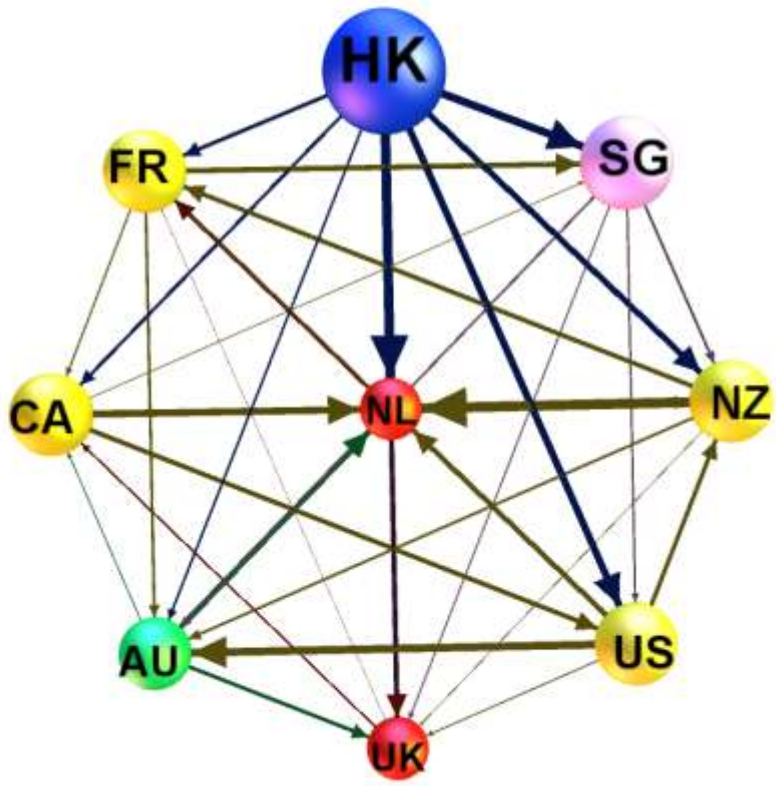


**Figure 6. Information flow network based on pairwise transfer entropy on 22 October 2008**

These results provide new insights into the exact nature of the information flow during the crisis. It reveals the leading role of the US real estate market developments together with the high integration of the US with the global markets. The evidence also reveals the relatively protected nature of the Asian real estate markets during the crisis, as the information spillover was more from the Asian markets to the other nodes than from other parts of the network to these markets.

The other major event apart from the global financial crisis of 2008 was the UK Brexit referendum on 24 June 2016. On this day, Britain took a historic vote to leave the European Union, stunning Europe and causing a shock which was felt across the globe. We capture the precise flow of information on that day within the global real estate markets, using our modelling framework.

The pairwise transfer entropy on 24 June 2016 is presented in Table 9. Clearly, the UK played a leading role in the transmission of information to the other nodes in the network. We find that the "To" entropy of the UK is 0.902, which is followed by that of the US (0.900). In contrast, Australia and Canada were the leading receivers of information from the network. In fact, in the case of Hong Kong, where we find the net transfer entropy to be positive (net information transmitter) for the full sample as well as in the midst of the financial crisis, the net transfer entropy on 24 June 2016 is -0.117 (net information receiver). These results corroborate the anecdotal evidence of the leading role of Britain and the reactionary mode of the Asian markets.

**Table 9. Pairwise transfer entropy on 24 June 2016**

| | AU | CA | FR | HK | NL | NZ | SG | UK | US | From |
|---|---|---|---|---|---|---|---|---|---|---|
| **AU** | 0 | 0.099 | 0.209 | 0.244 | 0.112 | 0.053 | 0.091 | 0.314 | 0.260 | 1.382 |
| **CA** | 0.221 | 0 | 0.157 | 0.014 | 0.084 | 0.017 | 0.029 | 0.095 | 0.112 | 0.729 |
| **FR** | 0.110 | 0.048 | 0 | 0.036 | 0.023 | 0.072 | 0.060 | 0.030 | 0.099 | 0.479 |
| **HK** | 0.106 | 0.060 | 0.118 | 0 | 0.119 | 0.121 | 0.001 | 0.094 | 0.032 | 0.651 |
| **NL** | 0.003 | 0.036 | 0.049 | 0.112 | 0 | 0.147 | 0.134 | 0.094 | 0.085 | 0.662 |
| **NZ** | 0.087 | -0.014 | 0.034 | 0.040 | 0.072 | 0 | -0.018 | 0.177 | 0.034 | 0.411 |
| **SG** | 0.002 | 0.067 | 0.065 | 0.073 | 0.075 | 0.055 | 0 | 0.096 | 0.119 | 0.551 |
| **UK** | 0.220 | 0.092 | 0.047 | -0.042 | 0.123 | 0.182 | 0.094 | 0 | 0.159 | 0.874 |
| **US** | 0.096 | 0.054 | 0.165 | 0.055 | 0.075 | 0.006 | 0.083 | 0.001 | 0 | 0.536 |
| **To** | 0.845 | 0.443 | 0.843 | 0.534 | 0.682 | 0.652 | 0.473 | 0.902 | 0.900 | 0 |
| **NET** | -0.538 | -0.286 | 0.365 | -0.117 | 0.021 | 0.241 | -0.078 | 0.028 | 0.364 | 0.697 |

These results are reflected visually in the information flow network (Figure 7) on 24 June 2016. The UK, along with the US, are ranked highest in the network hierarchy, with each having the out-degree of seven. While Hong Kong played an important role as information transmitter in the 2008 financial crisis as well as for the full sample period, here it is ranked second-last, with the out-degree of two, followed by Australia. Thus, while Hong Kong was an information transmitter in other periods, it was an information receiver on 24 June 2016.

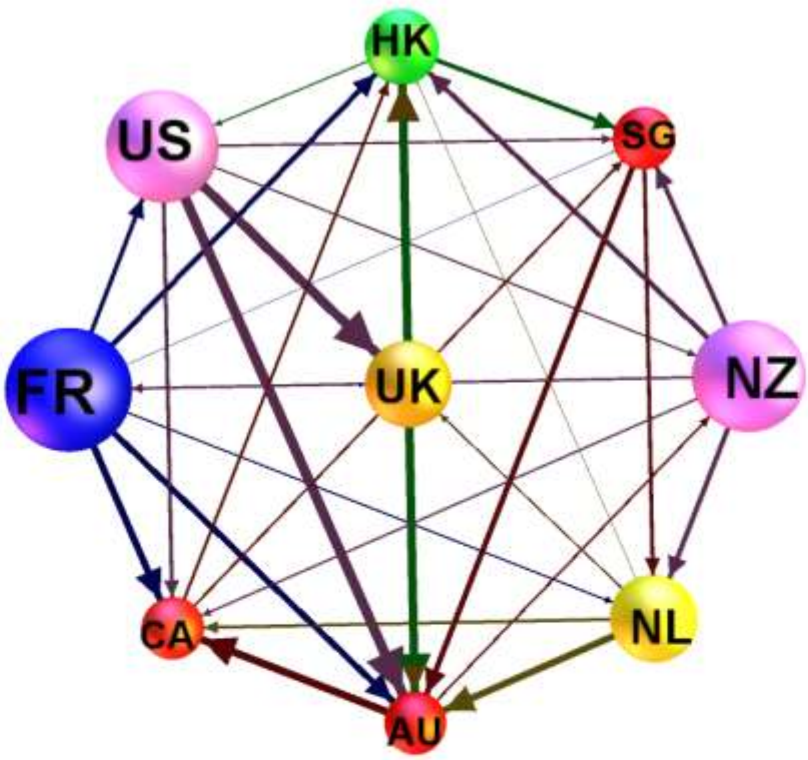


**Figure 7. Information flow network based on pairwise transfer entropy on 24 June 2016**

## 5. Conclusions

In this study, we explore the detailed flow of information within the network of leading real estate markets across the world. We develop an entropy-based network for the global real estate investment trust market. One of the major advantages of our approach is that it is simple and yet flexible in accommodating the network connections among a large number of components of the network system. We also employ both static and dynamic approaches to model the underlying structural changes which the international real estate market has witnessed over time.

Evidence suggests that the greatest pairwise transfer entropy is from the US to Australia, whereas France, the Netherlands, New Zealand and Singapore act as the largest information recipients in the network. The results of our time-varying analysis suggest that the flow of information measured by the total transfer entropy exhibits a declining trend. In this sense, the evidence supports the decoupling hypothesis for the international real estate markets. Our analysis also reveals the presence of very different information network dynamics during the 2008 crisis and during Britain's referendum to leave the European Union. To put it differently, our analyses highlight the need to account for REIT market interconnectedness using a time-varying (rolling-window) approach rather than full-sample methods to obtain accurate inferences about spillovers. In sum, while the importance of the US, which has the most mature REIT market, cannot be ignored in being the main transmitter of shocks to the REITs of other economies, from time to time, especially during periods of economic turbulence, some other REIT markets can also end up playing important leading roles in transmitting shocks. This finding would remain uncovered unless a time-varying analysis were to be pursued.


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