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Australian Macro-Financial Connectedness

A Study of Dynamics and Determinants

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Declaration

I declare that this thesis is my own work and that, to the best of my knowledge, it contains no material which has been written by another person or persons, except where acknowledgement has been made. This thesis has not been submitted for the award of any degree or diploma at the University of New South Wales Sydney, or at any other institute of higher education.

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Max Formato
22nd November, 2019

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Abstract

I investigate dynamics and determinants of Australian macro-financial connectedness from 1995Q1 to 2018Q4. I focus primarily on volatility spillovers between Australia's real economy and domestic bond, equity and housing markets. To chronicle dynamics, I apply the generalised Diebold-Yilmaz spillover framework (2012). To uncover determinants, I employ time-segmented regression techniques. I document substantial short- and medium-run fluctuations in connectedness that coincide with known macro-financial events and conditions. General levels of connectedness are found to increase in the lead-up to the 2008–09 Global Financial Crisis. The prevalence of the bond market in terms of shock transmission grows distinctly over the sample period, as does the relevance of the domestic term spread in explaining dynamics. Dynamics of Australian macro-financial connectedness appear best explained between 2003Q1 and 2010Q4, with unemployment generally demonstrating the most predictive ability. Consumer sentiment and equity market volatility are also found to display consistent importance over the full period of analysis. The results of this study are acknowledged to have critical implications for macro-prudential regulators and various stakeholders in the finance industry.

"One can safely argue that there is a hole in our knowledge of macro financial interactions; one might also argue more controversially that economists have filled this hole with rocks as opposed to diamonds; but it is harder to argue that the hole is empty."

- Ricardo Reis (2018)

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Chapter 1
Introduction

Heightened integration within and between economic and financial markets has led to more pervasive shock diffusion in recent decades. The Global Financial Crisis (GFC) illuminated the dangers associated with growing market integration. Since then, vast literature has aimed to address issues concerning market stability and crisis avoidance. In particular, researchers have focused on topics involving financial spillovers and global business cycle synchronisation. Surprisingly however, little attention has been dedicated to the study of macro-financial spillovers at the national level, and even less, in the context of the Australian economy.

A macro-financial spillover is an effect that stems from a seemingly unrelated event in one macro-financial context bearing impact on another. An example of this is a shock in Australia's equity market propagating changes in gross domestic product figures. These interdependencies are examples of macro-financial 'connectedness' in a more general sense. A sound understanding of the relationships between financial markets, and those between the financial and real sectors of the economy, is critical when formulating macroprudential policy. A firm awareness of historical macro-financial interactions may also enable better risk management and investment strategising by portfolio managers.

This thesis chronicles dynamics and identifies potential determinants of Australian macro-financial connectedness between 1995Q1 and 2018Q4. To analyse dynamics and historically document spillovers, I employ the generalised vector autoregressive framework proposed by Diebold and Yilmaz (2012). To facilitate explanatory analysis, I use time-segmented regression techniques to compare the predictive abilities of a set of potential macroeconomic and financial determinants.

My analysis of dynamics unveils several major findings. First, fluctuations in macro-financial connectedness are more prevalent in the short- and medium-run relative to the long-run. Second, variations in spillover indices coincide with known macro-financial events and conditions. Third, general levels of connectedness tend to rise in periods leading up to crises. Fourth, the bond market becomes a more prominent shock transmitter over the sample period.

Results obtained during explanatory analyses of macro-financial connectedness are also plentiful. Of the variables considered, I find that unemployment, consumer sentiment, equity market volatility and the term spread generally hold the most power in explaining dynamics. Contrastingly, economic growth and Australian Dollar return demonstrate comparatively less predictive abilities. I also note that general levels of explanatory power are greatest between

2003Q1 and 2010Q4, and smallest from 2011Q1 to 2018Q4. Macroeconomic factors are found to assert explanatory dominance over financial factors in the period leading up to the GFC. Of the various directional associations between spillover metrics and explanatory variables identified in Chapter 4, of note is the consistent negative association between equity market volatility and aggregate macro-financial connectedness.

I make several contributions to the literature of empirical macro-finance. First, I apply established econometric methods for spillover analysis to the Australian economy. These stem from Diebold and Yilmaz's (2012) seminal paper which incorporates the generalised variance decomposition techniques of Pesaran and Shin (1998) to compute previously introduced measures of connectedness (see Diebold & Yilmaz, 2009). Second, I extend the scope of traditional analysis via the inclusion of macroeconomic variables. This addition diverges from recent research on solely *financial* spillovers, thus allowing me to examine the broader topic of *macro-financial* connectedness in Australia. Third, I add to the emerging body of connectedness literature by incorporating housing market data in my analysis. This is opposed to exclusively using bond and equity market data as common in related studies.

The remainder of this paper is structured as follows. Chapter 2 provides a review of associated literature and establishes the relevance of this body of work. Chapter 3 provides an analysis of historical dynamics of Australian macro-financial connectedness. Chapter 4 explores potential determinants of this connectedness over the sample period. Chapter 5 presents a discussion of applications and limitations of this study, as well as suggested avenues for future research.

Chapter 2
Literature Review

Recent decades have witnessed a rising interdependence between the financial and real sectors of the economy. These trends have been identified at both national and international levels. Consequentially, economies have become increasingly prone to the spread of market distress via local and foreign-originating shocks. The potential ramifications of more lucid shock transmission were recently evident in the turmoil associated with the 2008–09 Great Recession.

Coinciding with the rapid integration of world economies, the topic of business cycle synchronisation garnered greater attention following the 1997 Asian Financial Crisis (AFC). Similarly, cointegration between global financial markets also became a more established research topic in the years following. These trends in research became even more magnified following the GFC (Cochrane, 2017). While co-movement in international markets and spillovers in the financial sector have attracted heavy research focus, the interplay between the real and financial sides of the economy has received comparatively little.

2.1 Defining 'Connectedness' & 'Spillovers'

In the literature of financial econometrics, the terms 'connectedness' and 'spillovers' have both been used to describe the outcomes of the interplay between an economy's real and financial sectors. I use both words in an equivalent fashion to mutually describe such outcomes.

'Spillovers' may be interpreted as illustrations of the 'connectedness' of any given system. The concept of 'connectedness' should be interpreted denotatively; it describes the state of having a link or relation to something. 'Spillovers' refer to events originating in one context bearing impact on the occurrences in another. For example, changes in equity markets impacting variations in quarterly gross domestic product (GDP) figures. In this case, macro-financial spillovers may be understood to represent a more general macro-financial connectedness associated with a given system.

2.2 Financial Connectedness

Although a broad subject, De Bandt and Hartmann's (2000) definition of systemic risk is oft-cited and concerns the propagation of events from one financial institution, market or system, to another. Topics involving systemic risk have direct policy implications for central banks, financial regulators, governments and monetary authorities (see Acemoglu, Ozdaglar, & Tahbaz-Salehi, 2015; Gai, Haldane, & Kapadia, 2011). Findings concerning systemic risk have the capacity to influence regulatory policy that aims to minimise systemic vulnerabilities and crisis likelihood.

Being closely associated with the study of systemic risk in general, the topic of financial connectedness has remained at the forefront of emerging research. Research on financial connectedness may be divided into two primary branches. The first branch aims to study the interconnectedness of firms and institutions at an individual-level, often via the use of structural models. Recent studies have used network models to examine the bilateral flows in assets and liabilities between groups of institutions (see Acemoglu et al., 2015; Anand, Gai, Kapadia, Brennan, & Willison, 2013; Markose, Giansante, & Shaghaghi, 2012). The second branch aims to study interconnectedness at the national and international level, often via the use of non-structural models. Such work includes the development and application of statistical measures to quantify and explain changes in systemic risk. Significant advances in this area include the CoVaR methodology developed by Adrian and Brunnermeier (2016), the dynamic equicorrelation model proposed by Engle and Kelly (2011), and the spillover frameworks introduced by Diebold and Yilmaz (2009, 2012, 2013, 2014).

Significant literature on financial spillovers in general predates work on macro-financial spillovers. A historical awareness of financial spillovers has been emphasised as vital for the design of macroprudential and other crisis-avoidance regulatory policy (see Brunnermeier, Gorton, & Krishnamurthy, 2011). Empirical studies have documented financial spillovers at both the institutional and market levels. This is the case on both a national and international scale. Studies have found large time variation in the level of financial spillovers, often tied to conditions within local financial markets. Financial spillovers have been found to increase in magnitude during periods of heightened volatility and systemic crisis (see Diebold & Yilmaz, 2012; Engle & Kelly, 2011). Noteworthy cross-sectional variation has also been observed in terms of certain institutions and countries being greater transmitters of shocks than others (see Adams, Füss, & Gropp, 2014). Consequentially, shock transmission analysis has been advocated as a potential tool to quantify connectedness, identify sources of spillovers, and assess systemic risk as a whole.

2.3 Macro-Financial Linkages

Existing studies that examine spillovers within financial markets have typically overlooked the established links between the real sector and financial sector. Preceding literature suggests that this has led to critical omissions in understanding spillover structures and the topic of systemic risk (see Borio & Drehmann, 2011). Key discoveries in theoretical work also implicitly champion the importance of investigating macro-financial spillovers. For instance, Bernanke, Gertler, and Gilchrist's (1996) proposition of the financial accelerator suggests linkages between financial markets and the real economy may spur adverse feedback loops. Such loops may potentially catalyse macro-financial crises.

Relations between macroeconomic fluctuations and financial market activity are a central focus of applied macro-finance and burgeoning area of research. Empirically, the ways in which financial market developments may influence activity in the real economy are well documented. Almeida and Campello (2007) and Ivashina and Scharfstein (2010) document how corporate investment may weaken as a result of a reduction in financial firms' willingness to grant credit to the private sector. Conversely, the impacts of macroeconomic shocks on non-financial firms and their associated stock valuations are also well established (see Jermann & Quadrini, 2012).

While the links between the real economy and financial markets are pronounced, little work has been dedicated to measuring spillovers between the two. Cochrane's (2017) literature survey indicates that few studies centre on the measurement of spillovers in comparison to their identification. Popular research in the vein of identification concerns the impact of macroeconomic news on behaviour in financial markets. These include the studies of Green (2004), Brenner, Pasquariello, and Subrahmanyam (2009), and Jiang, Konstantinidi, and Skiadopoulos (2012). Other studies have concentrated on the impact of financial conditions on macroeconomic outcomes. For instance, Ramcharan, Verani, and Heuvel (2016) and Chauvet, Senyuz, and Yoldas (2015) document the influence of financial volatility on economic growth outcomes. Significant attention has also been dedicated to identifying macroeconomic determinants of returns and volatilities in asset prices. The studies of Engle and Rangel (2008), Paye (2012) and Engle, Ghysels, and Sohn (2013) find that the performance of indicators including GDP and inflation bear deterministic impact on financial market performance.

These strands of empirical macro-finance provide critical insights and document the fundamental links between aspects of financial markets and the real economy. The aforementioned studies, however, do not directly comment on the magnitudes, structures and trends in macro-financial connectedness in a general sense. Moreover, they tend to only consider unidirectional links between specific subjects of interest rather than macro-financial systems as a whole. This is opposed to incorporating multi-directional frameworks that may be expected to better explain the likely complex relationships between the real and financial sides of the economy.

2.4 Empirical Australian Macro-Finance

The growing impetus on topics within applied macro-finance has been accompanied by work focusing on the Australian economy. Australia-centric studies have largely aligned with previously mentioned research trends. Significant attention has been dedicated to exploring the synchronisation of Australia's business cycles with those of other countries in the Pacific Rim (see Hall, Kim, & Buckle, 1998) and the U.S. (see Crosby, 2003). Substantial literature has also focused on event-study approaches to explore the impact of domestic (see S.-J. Kim, 1996) and foreign (see Ellis & Lewis, 2001) macroeconomic news on Australian financial market activity.

Australia has also been the focus of several studies concerning cross-country spillovers between financial markets. These have paid particular attention to the links between Australia's equity market and that of its major trading partners (see S. Kim & In, 2002; Roca, 1999; Shamsuddin & Kim, 2003). Research has found the U.S. to be the most crucial transmitter of volatility shocks to the Australian equity market (see Karunanayake, Valadkhani, & O'Brien, 2010; Martin & Dungey, 2007). Similar conclusions have been reached in terms of the U.S.'s status as a transmitter of shocks between the two countries' bond, credit and foreign exchange markets (see Cheung, Fung, & Tsai, 2010; S.-J. Kim & Sheen, 2018; Kortian & O'Regan, 1996, respectively).

Albeit to a lesser extent, spillovers between separate domestic financial markets in Australia have been explored. For instance, Bhar (2001) segments Australia's financial sector by conducting an analysis of spillovers between spot and futures equity markets. Moreover, Dean, Faff, and Loudon (2010) document asymmetry in return and volatility spillovers between domestic bond and equity markets from 1992 to 2006.

The quantification of direct linkages between Australia's real economy and financial markets at the country-level is still nascent. This is despite several studies advocating for an enhanced understanding of macro-financial connectedness in order to develop domestic stabilisation policy (see Bakker et al., 2012; White, 2006). Long-run relationships between equity market and aggregate economic activity in Australia are established as statistically significant (see Chaudhuri & Smiles, 2004). Other studies confirm the role of domestic macroeconomic variables as determinants of variation in Australian stock, bond and foreign exchange markets (see Campbell & Lewis, 1998; Chen & Tseng, 2012; Kearney & Daly, 1998, respectively). Studies following the GFC demonstrate an increasing correlation between business cycle moments and financial variables in Australia (see Jordà, Schularick, & Taylor, 2016). As discussed above, these findings are consistent with those of international studies and are indicative of the fundamental relationships between the financial and real economic sectors of Australia.

2.5 Measuring Australian Macro-Financial Spillovers

Of the work that has attempted to measure macro-financial spillovers, much has been limited by the fact that the real side of the economy is often only analysed via financial data from non-financial firms (see Baur, 2012; Dungey, Luciani, & Veredas, 2013). This has included individual stock returns, rather than key macroeconomic indicators such as GDP, inflation and unemployment. It is difficult to draw policy implications from such analyses as policy-makers are likely to be more interested in the direct (rather than indirect) influence of financial activity on real economic activity (and vice versa).

Götz, Hecq, and Smeekes (2016) partially addresses this limitation by incorporating industrial production growth in their exploration of the links between financial market uncertainty and macroeconomic outcomes in the U.S. This study, however, focuses on statistically signifying causal connectedness rather than directly measuring macro-financial spillovers. Similarly, Guarda and Jeanfils (2012) compare national differences in the origination of shocks from the financial to the real economic sector. They, however, explore the role of financial market shocks in determining real economic outcomes rather than measuring historical trends in macro-financial connectedness.

More generally, of the few studies that document historical macro-financial spillovers (see Cotter, Hallam, & Yilmaz, 2017, for instance), none pay direct attention to the Australian economy. As such, the study of multi-directional macro-financial spillovers in the Australian economy is a critical and novel avenue of research that this paper intends to explore.

Chapter 3

Dynamics of Macro-Financial Connectedness

3.1 Empirical Strategy

The Diebold-Yilmaz (2009; 2012; 2014) framework has been used extensively to measure system interdependence. This has been particularly the case when studying financial spillovers. The framework is premised on examining the decomposition of forecast error variance to measure connectedness. This method is linked to the overarching econometric concept of variance decomposition: decomposing variable i's forecast error variance into fractions attributable to other variables within a given system. More so than statistical testing,Diebold and Yilmaz's approach is focused on measurement and has undergone various adaptions since its introduction.

3.1.1 An Orthogonal Approach to Connectedness

Vector autoregression models (VARs) are often used to forecast systems of interrelated variables. VARs model each endogenous variable within a system as a function of lagged values of all endogenous variables within the system. The general mathematical form of a VAR may be expressed as:

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + B x_t + \epsilon_t \tag{3.1.1}$$

where y_t is a k vector of endogenous variables and x_t is a d vector of exogenous variables. $A_1, \ldots, A_p$ and B are matrices of coefficients that are estimated. ϵ_t is a vector of error terms that are both uncorrelated with their own lagged values and uncorrelated with all right-hand side variables. It should be noted, however, that the innovations within vector ϵ_t may indeed be contemporaneously correlated with each other.

To measure connectedness in the Diebold-Yilmaz tradition, one first estimates a VAR and then computes an H-step-ahead forecast. One then decomposes a collection of variables by calculating forecast error variances at time t with respect to those within the system.

Let d_{ij}^H be the ij-th H-step-ahead forecast error variance. That is, the portion of variable i's H-step-ahead forecast error variance attributable to shocks in variable j. Note that variable i and variable j may, in fact, take the form of groups of variables. Also note that $d_{ij}^H, i, j = 1, \cdots N, i \neq j$. The notion that $i \neq j$ is vital in understanding that the Diebold-Yilmaz connectedness measures are based on "cross" — rather than "own" — connectedness.

As per Diebold and Yilmaz (2009), consider an N-dimensional data-generated process with orthogonal shocks. Assuming covariance stationarity, this may be represented by:

$$x_t = \Psi(L)u_t, \tag{3.1.2}$$

$$\Psi(L) = \Psi_0 + \Psi_1 L + \Psi_2 L^2 + \cdots + \Psi_p L^p,$$

$$E\left(u_t, u_t{}'\right) = I$$

It should be noted that there is no requirement for Ψ_0 to be diagonal. Contemporaneous aspects of connectedness are summarised in Ψ_0 while dynamic aspects are encapsulated in $\{\Psi_1, \Psi_2, \cdots\}$. To uncover and neatly encapsulate connectedness, Diebold and Yilmaz (2009) advocate for the transformation of $\{\Psi_1, \Psi_2, \cdots\}$ via variance decompositions. A connectedness table may be constructed to easily portray various measures of connectedness and their formation.

Table 3.1.1
Orthogonal Connectedness Table

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

The main $N \times N$ block in the upper-left corner of the table is termed a "variance decomposition matrix". Based on its composition, this table may be referred to as an "orthogonal decomposition matrix". The matrix is denoted by $D^H = \left[d_{ij}^H\right]$ and contains variance decompositions. The connectedness table augments D^H with a bottom row containing sums of columns, a rightmost column containing sums of rows, and a bottom-right element representing the grand average, where $i \neq j$ for all cases.

The measures of connectedness evidenced in the table are based on "cross" (i.e. "non-own") connectedness. As such, they focus on the off-diagonal entries of the variance decomposition matrix, D^H. From a connectedness perspective, the off-diagonal entries denote the relevant portions of the N forecast error variance decomposition. More specifically, the entries may be interpreted as measures of pairwise directional connectedness. In this manner, the pairwise directional connectedness from variable j to i may be defined as:

$$C_{i \leftarrow j}^H = d_{ij}^H \tag{3.1.3}$$

In general, it should be appreciated that $C_{i \leftarrow j}^H \neq C_{j \leftarrow i}^H$, and so $N^2 - N$ distinct pairwise directional connectedness measures exist for any given system. Such measures may be considered analogous to bilateral trade flows (i.e. imports and exports) for a set of N national economies.

To make characterisations of variables comprising any given variable pair, a net measure of connectedness may be attained from the preceding gross, pairwise directional measures. As such, net pairwise directional connectedness may be defined as:

$$C_{ij}^{H} = C_{j \leftarrow i}^{H} - C_{i \leftarrow j}^{H} \tag{3.1.4}$$

There exists $\frac{N^2-N}{2}$ distinct, net pairwise directional connectedness measures. These may be interpreted as analogous to bilateral trade balances between a set of N national economies.

I now pay specific attention to the off-diagonal row and column sums in the connectedness table rather than merely the individual entries of D^H. The sum of the table's off-diagonal elements represents the fraction of the H-step-ahead forecast error variance of a given variable stemming from shocks attributable to the system's other variables. That is, the set of *all* other variables, rather than only a single variable. Accordingly, the off-diagonal row and column sums (labelled "from" and "to", respectively) provide aggregate measures of directional connectedness.

Let K denote the set of 'all other variables' aside from a specified variable i. Total directional connectedness from all other variables K to variable i may thus be defined as:

$$C_{i \leftarrow K}^{H} = \sum_{\substack{j=1 \\ j \neq i}}^{N} d_{ij}^{H} \tag{3.1.5}$$

Total directional connectedness to all other variables K from variable j may be defined as:

$$C_{K \leftarrow j}^{H} = \sum_{\substack{i=1 \\ i \neq j}}^{N} d_{ij}^{H} \tag{3.1.6}$$

There exists $2N$ total directional connectedness measures comprised of N "to others" (i.e. "transmitted") and N "from others" (i.e. "received") measures. Such indices may be interpreted as analogous to total exports and total imports for each individual N national economies within a system.

Akin to the analysis of net total effects in the context of pairwise directional connectedness, net total effects may be analysed in the context of aggregate directional connectedness. Net total directional connectedness may be defined as:

$$C_{i}^{H} = C_{K \leftarrow i}^{H} - C_{i \leftarrow K}^{H} \tag{3.1.7}$$

There exists N net total directional connectedness measures. These may be interpreted as analogous to the total trade balances for each individual N national economies within a system.

Lastly, the grand total of the off-diagonal entries in D^H represents total connectedness. This is equivalent to the sum of the "to" row and "from" column and thus may be defined as:

$$C^H = \frac{1}{N} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} d_{ij}^H \tag{3.1.8}$$

There exists one *total* connectedness measure that essentially condenses connectedness within a given system into a single figure. This index may be interpreted as analogous to total global exports (or equivalently, total global imports). As this measure is constructed by taking the off-diagonal D^H variation with respect to total D^H variation (N), C^H will be expressed as a decimal share. Like the "to others" and "from others" aggregate measures, this means that the "total" connectedness measure is easily displayable in percentage format.

The orthogonal connectedness table enables simple elucidation of how the most disaggregated measures of connectedness (i.e. pairwise-directional) may be aggregated in ways that reflect total, directional connectedness within a given system. Clearly, different agents may naturally be more concerned with particular measures within this table. For instance, the government of a national economy i may be most interested in how the economy of another nation j is connected to it (i.e. via $C^H_{i \leftarrow j}$), or how all other national economies K are connected to it (i.e. via $C^H_{i \leftarrow K}$). In contrast, macroprudential regulators may be relatively more interested in the identification of systemically important nations j via comparative total directional connectedness analysis (i.e. via $C^H_{K \leftarrow j}$), or assessing aggregate system-wide connectedness in general (i.e. via C^H).

3.1.2 A Generalised Approach to Connectedness

Orthogonality guarantees that the variance of a weighted sum is an appropriately weighted sum of variances. As such, the orthogonal structural system discussed in Section 3.1.1 ensures the simple computation of variance decompositions. It should be noted, however, that reduced-form shocks are seldom orthogonal in nature. Therefore, assumptions must often be made in order to identify uncorrelated structural shocks from correlated reduced-form shocks.

To orthogonalise shocks, Diebold and Yilmaz (2009) employ a Cholesky-factor VAR identification popularised by Sims (1980). As noted in subsequent work, results based on this traditional identification are sensitive to variable ordering; this is particularly the case for measures of directional connectedness (Diebold & Yilmaz, 2012). Sensitivity to the ordering of variables arises because Cholesky-factor identification necessitates the assumption of a particular recursive ordering.

Similar to Cholesky-factor variance decompositions, generalised variance decomposition frameworks rely on a fundamentally data-based identification scheme. Most notably, generalised frameworks have the requisite assumption of normality of shock distributions. Such frameworks, however, are relatively advantageous in the sense that they are not sensitive to variable ordering.

Diebold and Yilmaz (2012) alleviate previously-encountered issues regarding variable ordering by implementing a generalised VAR approach. This approach stems from generalised variance decomposition methods introduced by Koop, Pesaran, and Potter (1996) and built on by Pesaran and Shin (1998). The generalised VAR approach produces variance decompositions that enable the presence of correlated shocks while being invariant to variable ordering. In this case, correlated shocks are accounted for by using the historically observed distribution of errors.

Following Diebold and Yilmaz (2012), consider a covariance stationary VAR(p):

$$y_t = \sum_{i=1}^{p} \phi_i y_{t-1} + \varepsilon_t \tag{3.1.9}$$

where y_t represents an $N \times 1$ vector of endogenous variables, ϕ_i represent $N \times N$ autoregressive coefficient matrices, and by assumption, $\varepsilon_t \sim (0, \Sigma)$ is a vector of independently and identically distributed (iid) error terms.

As the aforementioned VAR process is assumed to be covariance stationary, its moving average representation is denoted by:

$$y_t = \sum_{q=0}^{\infty} A_q \varepsilon_{t-q} \tag{3.1.10}$$

where A_q are $n \times n$ coefficient matrices that obey the recursion

$$A_q = \phi_1 A_{q-1} + \phi_2 A_{q-2} + \ldots + \phi_p A_{q-p} \tag{3.1.11}$$

with A_0 being an $n \times n$ identity matrix and $A_q = 0$ for $q < 0$.

In the context of the generalised VAR framework, the H-step-ahead forecast error variance decompositions, $\theta^g_{ij}(H)$ for $H = 1, 2, \ldots$ may be written as:

$$\theta^g_{ij}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h' e_i)} \tag{3.1.12}$$

where Σ is the variance matrix for the vector of errors ε, σ_{ii} is the standard deviation for the ith equation, and e_i is an $n \times 1$ selection vector with one as the ith element and zeros otherwise.

Similar to before, the main $N \times N$ block in the upper-left corner of Table 3.1.2 may be referred to as a "generalised variance decomposition matrix". The matrix is denoted by $\theta^g = \left[\theta^g_{ij}\right]$ and contains the variance decompositions. The connectedness table augments θ^g with a bottom row containing sums of columns, a rightmost column containing sums of rows, and a bottom-right element representing the grand average, where $i \neq j$ for all cases.

Table 3.1.2
Generalised Connectedness Table

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

In the context of generalised variance decomposition, shocks are not necessarily orthogonal. Consequentially, the sums of forecast error variance contributions do not necessarily sum to unity (i.e. the row sums of θ^g generally do not sum to 1). This resembles a complication relative to the aforementioned case of orthogonal shocks via Cholesky-factorisation. In the Cholesky case, variance decomposition computation was simpler based on the presence of unity in the summation of forecast error variance contributions.

Resolving this complication, Diebold and Yilmaz (2012) base their generalised connectedness measures on $\tilde{\theta}^g = \left[\tilde{\theta}^g_{ij}\right]$ rather than θ^g. That is, each entry in the variance decomposition matrix is normalised by its row sum so that:

$$\tilde{\theta}^g_{ij}(H) = \frac{\theta^g_{ij}(H)}{\sum_{j=1}^{N} \theta^g_{ij}(H)} \tag{3.1.13}$$

where, by construction, $\sum_{j=1}^{N} \tilde{\theta}^g_{ij}(H) = 1$ and $\sum_{i,j=1}^{N} \tilde{\theta}^g_{ij}(H) = N$. Following this normalisation process, the following connectedness table is constructed:

Table 3.1.3
Generalised & Normalised Connectedness Table

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

Similar to previously, the main $N \times N$ block in the upper-left corner of the table may be referred to as a "generalised and normalised variance decomposition matrix". The matrix is denoted by $\tilde{\theta}^g = \left[\theta^g_{ij}\right]$ and contains the variance decompositions. The connectedness table augments $\tilde{\theta}^g$ with a bottom row containing sums of columns, a rightmost column containing sums of rows, and a bottom-right element representing the grand average, where $i \neq j$ for all cases.

3.1.3 Measuring Connectedness

In a similar fashion to Section 3.1.1, generalised measures of connectedness may now be computed from $\tilde{\theta}^g_{ij}(H)$. Note that the following equations make use of the fact that $\sum_{I,j=1}^{N} \tilde{\theta}^g_{ij}(H) = N$.

The first estimate of interest is the fraction of a system's total H-step ahead error variance that may be attributed to shocks across variables. This is measured by the Diebold-Yilmaz aggregate (non-directional) 'total spillover index' which may be defined as:

$$S(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}^g_{ij}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}^g_{ij}(H)} \times 100 = \frac{100}{N} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}^g_{ij}(H) \tag{3.1.14}$$

where $S(H)$ measures the contribution of spillovers across N variables to the total forecast error variance. This index may be interpreted as the ratio of the sum of all off-diagonal elements in the variance decomposition matrix of all variables to the sum of all elements (i.e. both off-diagonal and own shock elements).

I then decompose the total spillover index into a set of directional measures via partial aggregation. The rationale for doing so is to better understand the multi-directional dynamics of shock transmission. Directional measures are able to be attained under the Diebold and Yilmaz (2012) approach as the generalised variance decompositions are invariant to variable ordering.

To calculate the spillovers received by variable i from all other variables K, I compute:

$$S_{i \leftarrow K}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}^g_{ij}(H)}{\sum_{j=1}^{N} \tilde{\theta}^g_{ij}(H)} \times 100 = \frac{100}{N} \sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}^g_{ij}(H) \tag{3.1.15}$$

where $S_{i \leftarrow K}(H)$ measures the fraction of a system's total H-step-ahead error variance that may be attributed to shocks received by variable i from all other variables K within the system.

To calculate the spillovers transmitted by variable i to all other variables K, I compute:

$$S_{K \leftarrow i}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}^g_{ji}(H)}{\sum_{j=1}^{N} \tilde{\theta}^g_{ji}(H)} \times 100 = \frac{100}{N} \sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}^g_{ji}(H) \tag{3.1.16}$$

where $S_{K \leftarrow i}(H)$ measures the fraction of a system's total H-step ahead error variance that may be attributed to shocks transmitted by variable i to all other variables K within the system.

The summation of $S_{i \leftarrow K}(H)$ (or $S_{K \leftarrow i}(H)$) for the set N 'from all other' (or 'to all other') variables is simply the value of the total spillover index, $S(H)$. Thus, this pair of directional measures may be interpreted as providing a deconstruction of total spillovers within the system.

The net spillovers from variable i to the aggregation of all other variables K within a system may be computed from these directional measures. This allows for the identification of 'net transmitters' ('net receivers') of shocks to (from) all other variables within the system. This is done by calculating:

$$S_{NiK}(H) = S_{K \leftarrow i}(H) - S_{i \leftarrow K}(H) \tag{3.1.17}$$

where a positive (negative) value of $S_{iK}(H)$ implies variable i is a 'net shock transmitter (receiver)' to (from) all other variables K. $S_{Nik}(H)$ is merely the difference between gross volatility shocks transmitted to and received from all other variables K with respect to i.

These directional measures enable an individual variable to be analysed in terms of connectedness to the aggregated set of all other variables within a system. In order to analyse the spillover dynamics between certain pairs of individual (or grouped) variables, pairwise analogues of the above measures may be computed. Such analogues enable the exploration of spillover dynamics that are not immediately clear when only considering aggregated measures. That is, for example, examining spillovers between equity market return volatilities and GDP growth volatilities.

Of most note is the analogue for net pairwise connectedness, which may be defined as:

$$S_{ij}(H) = \left(\frac{\tilde{\theta}^g_{ji}(H)}{\sum_{k=1}^N \tilde{\theta}^g_{jk}(H)} - \frac{\tilde{\theta}^g_{ij}(H)}{\sum_{k=1}^N \tilde{\theta}^g_{ik}(H)} \right) \times 100 = \frac{100}{N} \left(\tilde{\theta}_{ji}(H) - \tilde{\theta}_{ij}(H) \right) \tag{3.1.18}$$

where a positive value of $S_{ij}(H)$ implies variable i is a 'net shock transmitter' to a specified variable j. Conversely, a negative value of $S_{ij}(H)$ implies variable i is a 'net shock receiver' from a specified variable j. Such computations allow a particular variable to be identified as 'dominant' in terms of volatility transmission between any given pair of variables.

3.2 Description of Data

In the sections that follow, I apply Diebold and Yilmaz's (2012) above-described generalised framework to study Australian macro-financial connectedness. To do this, I work with variables that represent different aspects of the Australian economy. On the financial side of the Australian economy, I use data stemming from financial markets. On the real economic side, I use data stemming from macroeconomic indices. A summary of data sourcing for this section is provided in Table A.2.1 of Appendix A.

Much of the recent literature on connectedness examines financial spillover dynamics around the years of the 2008–09 GFC. While possible to focus exclusively on a similar time period, I choose to analyse Australian macro-financial connectedness on a longer-term horizon. The motivation for this is to better understand historical trends around a variety of known conditions and events.

The sample period of my constructed dataset spans from the 1st of January 1987 to the 31st of December 2018. This period of analysis therefore contains multiple noteworthy macro-financial events rather than solely the recent crisis. Of particular note, is the early 1990s national recession, the 1997 AFC and the 2001 Dot Com Bubble.

Consistent with existing literature on financial and macro-financial connectedness, I focus on return volatilities (hereafter, "volatilities"), rather than raw levels of return. It is often argued that volatility spillovers are most relevant in the contexts of financial and macro-financial analysis (Cotter et al., 2017). These arguments generally stem from the documentation of heightened financial volatility during periods of crisis (see, for instance, Schwert, 2011) and the importance of volatility to a multitude of stakeholders.

Soler (2009) identifies four key reasons for greater interest in volatilities relative to simple rates of return. First, policy-makers often rely on volatility estimates to gauge vulnerabilities in financial markets and economies as a whole. Second, as volatilities reflect risk exposure, an awareness of financial asset volatilities is essential in the optimisation of portfolio management strategies. Third, volatilities play a crucial role in the pricing of derivative securities. Fourth, the Basel Accord's Market Risk Amendment of 1996 demanded increased focus on volatility forecasting and related research areas.

Focusing on volatility spillovers is also advantageous based on the approximately Gaussian form of logarithmic return volatilities. This feature is particularly important in the context of spillover estimation, as Gaussianity is a requisite condition for the application of Section 3.1.2's generalised variance decomposition methods.

In line with these points, I focus my analysis and discussion primarily on spillovers in return and growth volatilities. Results associated with raw rates of return and growth are reserved for Appendix B.

3.2.1 Real Side of the Australian Economy

I use GDP as the primary representative variable for the real side of the Australian economy. This is based on its widespread use in related empirical literature and clear practical interest. Specifically, I use total, seasonally adjusted GDP by expenditure in constant prices. This data is obtained at a quarterly frequency from the Federal Reserve Economic Data (FRED) database provided by the Federal Reserve Bank of St. Louis.

I transform the original level series of GDP into quarter-on-quarter logarithmic (percentage) growth rates for the sample period. This is done based on the presumption that changes in variables on the financial side of the Australian economy are most likely to be related to relative (compared to absolute) movements in GDP. For consistency with the transformations of the ensuing financial variables, I square the logarithmic growth rates for each period to generate quarterly growth volatilities.

3.2.2 Financial Side of the Australian Economy

I obtain data from Australia's bond (BON), equity (EQU) and housing (HOU) markets to represent the financial side of the domestic economy. To approximate volatilities for the quarterly housing market data, I compute squared logarithmic rates of return. To approximate volatilities for the daily bond and equity market data, I implement a similar strategy used by Kothari, Lewellen, and Warner (2014). First, I generate weekly returns and then take the square root of the sum of squared weekly logarithmic returns. To compute quarterly volatilities, calculations are completed in 12-week blocks. An example of this approach for weeks 1 to 12 is provided below:

$$\text{Quarterly Return (Weeks 1 to 12)} = \sqrt{\sum_{i=1}^{i=11} \left[\ln \left(\frac{\text{Weekly Return}_{i+1}}{\text{Weekly Return}_i} \right) \right]^2} \qquad (3.2.1)$$

Bond & Equity Market Data

I use the 10-year Australian government bond yield to represent the domestic bond market. I obtain daily middle rate data from Datastream. The choice to focus on bonds with a single tenure is made to keep empirical analysis concise. The choice to focus on bonds with a 10-year maturity seems most appropriate given the relatively long-term nature of this study. Previous studies, however, suggest that the dynamics of macro-financial connectedness may depend on the type of bond used for analysis (Brenner et al., 2009). Whether or not this is indeed the case is a question left to future researchers.

I use All Ordinaries index (ASX:XAO) data to represent the Australian equity market. The index is weighted by market capitalisation and tracks the 500 largest companies on the Australian Securities Exchange. I obtain data at a daily frequency from Yahoo! Finance.

Transformation of Daily Financial Data

I aggregate daily bond and equity market data to the quarterly frequency of the housing market and real economic variables. This is done to avoid complications stemming from the use of mixed-frequency data in the Diebold-Yilmaz spillover framework. These complications and the limitations of this aggregation scheme are discussed further in Section 5.2.

In order to construct these quarterly series, I first transform the aforementioned daily financial data into weekly logarithmic return volatilities. This is done to circumvent issues that result from deterministic time variation in the number of days that comprise different months. As each quarter contains three months, such deterministic time variation may be expected to impact the construction of quarterly financial series if not addressed.

To account for such issues, I begin by matching the trading dates associated with the two subsamples of financial data. I then follow Cotter et al.'s (2017) approach in producing weekly series for the bond and equity variables whereby each month contains a consistent and constant four weeks. This approach is reliant on the creation of 'pseudo weeks' as an alternative to standard (7-day) calendar weeks.

'Pseudo weeks' are generated by dividing a given month's trading days into four sub-periods (hereafter, "pseudo weeks") whose lengths are as close as possible to equivalence. For example, a month with 20 trading days contains four 5-day pseudo weeks (i.e. 5-5-5-5) while a month with 22 days is divided into two 5-day and two 6-day pseudo weeks (i.e. 5-5-6-6). It should be noted that in this study, pseudo weeks generally contain either 5 or 6 trading days. This is in line with the fact that there are 21 (matched) trading days, on average, per month within the sample period. Some exceptions to these cases exist; most common is the month of February which has a uniquely shorter relative length. Months with an atypically greater number of non-trading days (e.g. April due to Easter holidays) also tend to contain a 4-day pseudo week.

The ordering of pseudo week splits is randomised on a monthly basis for statistical soundness. This means, for instance, that a month containing 23 trading days (i.e. three 6-day and one 5-day pseudo weeks) has an equal chance of being ordered as a 5-6-6-6, 6-5-6-6, 6-6-5-6 or 6-6-6-5 split. To ensure periodic coherence, pseudo week split orderings for Australian bond and equity market data are implemented identically. This ensures that the formation of each pseudo-weekly financial series is synchronised in terms of calendar time.

Weekly returns are then calculated using the pseudo-weekly series of bond and equity data. As before, quarterly logarithmic return volatilities are generated by taking the square root of the sum of squared weekly logarithmic returns for each variable in 12-week blocks.

Housing Market Data

I use the Established House Price Index to represent the Australian housing market. Specifically, I use the weighted-average form of this index affiliated with the nation's eight capital cities. The data is sourced at a quarterly frequency from the Australian Bureau of Statistics (ABS).

Notably, the methodology of ABS House Price Index estimation changed from the December quarter of 2013. Such alterations represent a clear limitation in terms of the quality of historical housing data. Revised data using the newer methodology is available from the March quarter of 2002 to the end of the sample period. To overcome this obstacle of data availability, I splice the series obtained before and after the 2013Q4 change to index estimation. I use pre-change quarter-on-quarter logarithmic rates of return in the Established House Price Index to extrapolate the post-change series from 2001Q4 back to 1987Q1. This results in the construction of a dataset for the full sample period of 1987Q1 to 2018Q4. Logarithmic rates of return are then squared to produce a series of quarterly domestic housing market volatility.

3.3 Preliminary Results

3.3.1 Descriptive Statistics of Variables

Table 3.3.1 displays the correlation matrix (a) and summary statistics (b) for the financial return volatilities and real economic growth volatilities of the previously described variables. These variables are representative of the bond market (BON), equity market (EQU), housing market (HOU) and real economy (GDP). Results in both tables are obtained for the full sample period of 1987Q1 to 2018Q4.

Table 3.3.1
Summary Descriptive Statistics & Correlation Matrix — Volatilities

	BON	EQU	HOU	GDP
BON	1.000			
EQU	0.052	1.000		
HOU	0.086	0.042	1.000	
GDP	-0.112	0.213	0.023	1.000

(a) Correlation Matrix — Volatilities

	BON	EQU	HOU	GDP
Mean	0.070	0.057	8.86E-04	9.67E-05
Median	0.066	0.051	2.84E-04	5.55E-05
Max.	0.178	0.360	0.010	8.51E-04
Min.	0.026	0.009	0.000	8.96E-09
Std. dev.	0.029	0.035	0.002	1.22E-04
Skew	1.081	5.577	3.663	2.809
Kurt.	4.113	45.535	17.900	14.183
J-B.	31.516***	10312.810***	1470.393***	835.210***

(b) Summary Descriptive Statistics — Volatilities

Table contains the correlation matrix (a) and summary descriptive statistics (b) of the representative variables used in spillover estimation in Chapter 3. Rejection of the joint null hypothesis for the Jarque-Bera (J-B.) test that skewness and excess kurtosis is zero is denoted by the following levels of statistical significance: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Each observation in the financial series (i.e. BON, EQU and HOU) has been transformed into a return volatility in percentage format. Each observation in the real economy series (i.e. GDP) has been transformed into a growth volatility in percentage format. The variable "BON" represents the Australian bond market using 10-year Australian government bond yield data. The variable "EQU" represents the Australian equity market using All Ordinaries index data. The variable "HOU" represents the Australian housing market using Established House Price Index data. the variable "GDP" represents the Australian real economy using GDP data. All variables are at the quarterly frequency for the full sample period of 1987Q1 to 2018Q4. A full description of data is provided in Section 3.2 with further details in Table A.2.1 of Appendix A.

Several initial observations may be made. First, the levels of correlation between the volatilities of the four variables are reasonably low over the full sample period. The strongest recorded correlation exists between the real economy and equity market (+0.213) followed by the real economy and bond market (−0.112). Second, all variables exhibit positive skewness in conjunction with excess kurtosis. The Jarque-Bera test statistics reinforce this notion, strongly rejecting the presence of normality in each variable's distribution. This finding is consistent with time-series literature (see Cont, 2001).

The rates of return and growth for the financial and real economic variables, respectively, along with their volatilities, are plotted in Figure 3.3.1. Key economic and financial events are clearly visible in the form of significant surges in volatility and substantial declines in growth and return levels. Examples of these events include the Black Monday Crash of 1987, the 1990–91 national recession, the 1997 AFC, the Dot Com Bubble, the September 11 attacks, the 2008–09 GFC, and the 2015 Chinese stock market crash. A full recount of key macro-financial events over the sample period is provided in Table A.1.1 of Appendix A.

Figure 3.3.1's volatility plots display highly persistent dynamics, as consistent with past research including Andersen, Bollerslev, Christoffesen and Diebold (2016). Such persistence is observable in the return plots in the form of clustering. It is interesting to note that periods of economic and financial crises are often associated with surges in volatility — this is particularly the case for the bond and equity markets. Examples of these surges are particularly visible in quarters associated with the 2008–09 GFC.

Between 1987Q1 and 2018Q4, a gradual increase in Australian bond market volatility is noticeable. This long-run trend is accompanied by several periods of especially heightened instability, particularly towards the end of the sample period. Bond market volatility has increased markedly since the GFC. While the equity market has experienced similar spikes in volatility over the same period, no clear trend is evident. The housing market is also bereft of a well-defined trend in volatility over the sample period. Episodes of surges in housing market volatility are greater in relative magnitude than those documented in the bond and equity markets. Plots for the real economy series document large variability in quarterly growth volatilities; bursts in volatility are generally smaller in magnitude towards the end (relative to the beginning) of the sample.

Figure 3.3.1

Time Series Plots of Financial and Real Economic Series

The financial (All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index) and real economy (GDP) series are plotted for the full sample period 1987Q1 to 2018Q4. Returns and return volatilities are display in percentage terms at quarterly frequencies. Return volatilities are constructed using the approaches detailed in Section 3.2. GDP is expressed as a quarterly series of logarithmic percentage growth rates. Volatility of GDP growth is computed by squaring the logarithmic growth rates for each quarter-on-quarter period.

3.3.2 Stationarity Tests

As the Diebold-Yilmaz framework necessitates covariance stationarity, I conduct Augmented Dickey-Fuller (ADF) tests on the variables of interest. The null hypothesis of the ADF test is that a given series contains a unit root; the alternative implies that the series is stationary. Table 3.3.2 contains the results of these ADF tests for each volatility series of the representative variables. Table B.1.2 of Appendix B contains test results for each variable's return (or growth) series.

Table 3.3.2
Augmented Dickey-Fuller (ADF) Tests — Volatilities

	BON	EQU	HOU	GDP
Intercept	-4.941***	-4.844***	-5.807***	-10.843***
Trend & Intercept	-6.157***	-4.737***	-5.789***	-11.664***
None	-0.834	-1.988**	-4.416***	-1.513

Table displays Augmented Dickey-Fuller tests for stationarity for each of the previously specified representative variables used in volatility spillover estimation in Chapter 3. Rejection of the null hypothesis that a unit root is present in the series is denoted by the following levels of statistical significance: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. All variables are at the quarterly frequency for the full sample period of 1995Q1 to 2018Q4. A full description of data is provided in Section 3.2 with further details in Table A.2.1 of Appendix A.

The ADF test results for both the return and volatility series of each variable reject the null of the presence of a unit root. In the case of returns, stationarity is implied at least the 10% level for all variables and all test specifications. In the case of volatilities, rejection of the null occurs for every variable with almost every specification, at the 1% significance level. Failure to reject the null occurs when the test is conducted with no trend and no intercept for the bond market and real economy series.

The volatility plots presented in Figure 3.3.1 suggest that ADF test results with an intercept are most appropriate. Accordingly, the failures to reject the null in the above-mentioned instances are not a cause for concern. As such, there exists no hindrance to the application of the Diebold-Yilmaz spillover framework.

3.3.3 Order of Vector Autoregression Model

Prior to initial spillover estimation, I use the Akaike information criterion (AIC) and Bayesian information criterion (BIC) to guide the choice of order for VAR modelling (see Akaike, 1974; G. Schwarz, 1978). I exhibit the associated criterions for VAR models between 2 and 6 lags in Table 3.3.3.

Table 3.3.3
Comparison of Information Criterion for VAR — Volatilities

	2 Lags	3 Lags	4 Lags	5 Lags	6 Lags
Akaike information criterion (AIC)	-34.161	-34.193	-35.217	-35.125	-35.039
Bayesian information criterion (BIC)	-33.350	-33.017	-33.670	-33.204	-32.740

Table displays the Akaike information criterion (AIC) and Bayesian information criterion (BIC) values for VAR models with various lags. Each model contains all previously specified representative variables for volatility used in Chapter 3 ("BON", "EQU", "HOU", "GDP"). All variables used in the models are employed at the quarterly frequency for the full sample period of 1995Q1 to 2018Q4.

As evident, both criterions are smallest when 4 lags are specified for the VAR model using volatilities. As such, and for consistency, I incorporate 4 lags during VAR specification for the measurement of spillovers in raw rates of return (and growth) and their associated volatilities. Historical spillover dynamics are largely found to be consistent using alternative lag specifications. This is the case for both returns and volatilities. Sensitivity of results to VAR ordering are provided in Sections A.3 and B.4 of Appendix A and B. Robustness to alternative specifications are discussed further in Section 3.4.2.

3.3.4 Specification of Forecast Horizon

A forecast horizon must also be specified in the process of computing variance decompositions. The choice of horizon length entails a trade-off between assessing 'short-run' and 'long-run' spillover dynamics. As forecast horizons lengthen, short-run conditioning information becomes less influential. As the forecast horizon approaches infinity, an unconditional variance decomposition is obtained (Diebold & Yilmaz, 2014).

When conducting primary analysis, I choose an intermediary horizon of 3-quarters. This choice is motivated by the use of quarterly data and focus on dynamics over a three-decade period. Other studies more concerned with short-run dynamics tend to choose a relatively smaller forecast horizon (see Han, Kordzakhia, & Trueck, 2017). I find that spillover dynamics are broadly consistent among forecast horizons between 2 to 5 quarters. These results are provided in Sections A.4 and B.5 of Appendix A and B. Intuitively, it should be appreciated that large forecast horizons bring about a greater chance that variables in a system may be connected. This likelihood is often reflected in robustness checks, with lengthening forecast horizons being associated with larger magnitudes of estimated connectedness.

3.4 Primary Results

3.4.1 Static Analysis of Connectedness

Table 3.4.1 displays the static connectedness table introduced and discussed in Section 3.1. The results in this table depict connectedness over the full sample period. As with the dynamic estimates provided in the next section, these results are based on VAR models of order 4 and generalised variance decompositions of 3-quarter-ahead volatility forecast errors. I now dissect the static results in Table 3.4.1 beginning with the most disaggregated measures.

Table 3.4.1
Static Connectedness Table — Volatilities

	Real Economy	Bond Market	Equity Market	Housing Market	Directional *FROM* Others
Real Economy	95.818	2.046	1.824	0.313	4.182
Bond Market	1.531	83.296	13.646	1.527	16.704
Equity Market	1.238	12.981	81.729	4.052	18.271
Housing Market	0.092	4.934	3.433	91.541	8.459
Directional *TO* Others	2.861	19.961	18.903	5.892	
Directional Including Own	98.678	103.257	100.632	97.432	*Total* Spillover Index: 11.904%
Net Directional Connectedness	-1.322	3.257	0.632	-2.568	

Table displays the connectedness measures specified in Table 3.1.3 of Section 3.1. All estimates are computed using the return volatilities of financial variables (i.e. BON, EQU and HOU) and growth volatilities of the real economy variable (i.e. GDP). All figures are expressed in percentage terms. Each cell in the upper-left 4x4 matrix displays the relative contribution of the 'column' variable to the variance of the forecast error for the 'row' variable. The "Directional *FROM* Others" column displays the total forecast error variance portions of the row variables due to shocks from other variables. The "Directional *TO* Others" row displays the total forecast error variance portions of the column variables to the forecast error variance of all other variables. Each cell in the "Directional Including Own" row displays the total forecast error variance portions of a given to the forecast error variance of all other variables and the total forecast error variance attributable to the given variable itself. Each cell in the "*Net* Directional Connectedness" row displays the net difference between the corresponding cells in the "Directional *TO* Others" row and the "Directional *FROM* Others" column. The "*Total* Spillover Index" is the average of all elements in the "Directional *TO* Others" row (or equivalently, the "Directional *FROM* Others" column) multiplied by 100 per cent.

Net Pairwise Connectedness

The extent of directional connectedness between any pair of variables within the system is embodied in the off-diagonal elements of the 4 x 4 matrix in Table 3.4.1. For instance, the '13.646' value at the intersection of the third row and fourth column signifies the percentage of forecast error variance of bond market volatility that is due to shocks from the equity market.

One key observation that may be made is that the greatest pairwise directional connectedness occurs between Australia's bond and equity markets. The largest pairwise relation of directional connectedness arises from the equity market to the bond market (13.646%). The second largest relation occurs from the bond market to the equity market (12.981%). Although these percentages are quite low, they far exceed the third largest result of pairwise directional connectedness: spillovers from the bond market to the housing market (4.934%).

Directional Connectedness

I now consider the partial aggregated directional spillover results. The figures in the far right "Directional *FROM* Others" column represent the portion of volatility shocks received from other variables in the total variance of the forecast error for each variable. They signify the total directional connectedness from the volatilities of all other variables to the volatilities of a single variable. Each figure is equal to 100% minus a variable's own share of the total forecast error variance.

The "Directional *FROM* Others" column exhibits figures ranging from 4.182% to 18.271% for the four variables. This implies that volatility shocks from all other variables j to a given variable i differ on a case-by-case basis. Gross directional volatility spillovers from all other variables to the bond and equity markets are the largest at 16.704% and 18.271% each, respectively. The volatilities of these two variables are thus most affected by other volatilities in the system.

Similarly, the values in the "Directional *TO* Others" column represent the total directional connectedness from a single variable to all other variables in the system. They reflect each variable's contribution to the forecast error variances of other variables in the system. Substantial differences exist in these results, ranging from 2.861% for the real economy to 19.961% for the bond market. The bond and equity markets can be identified as the largest sources of gross directional volatility spillovers to all other variables, on average, over the sample period.

The values in the bottom-most row labelled "*Net* Directional Connectedness" denote the difference between total connectedness *to* all others and total connectedness *from* all others for any single variable. Intuitively, the positive net total directional connectedness of the bond (+3.257%) and equity (+0.632%) markets is indicative of their role as 'net transmitters' of volatility spillovers. Clearly, the bond market can be identified as the greatest average net transmitter of shocks in the system. Conversely, the housing market (−2.568%) and real economy (−1.322%) are found to be 'net receivers' of volatility spillovers. The housing market is the greatest average net recipient of shocks in the system.

Total Connectedness

The total spillover index provided in the bottom right corner of the table is a distillation of the aforementioned directional volatility spillovers. It is an overall description of the extent of system connectedness between 1987Q1 and 2018Q4. The index indicates that, on average across the full sample period, 11.904% of volatility forecast error variance for the four variables arises from spillovers. In other words, around 12% of changes in volatilities within the system are caused by the mutual influence of changes in the volatilities of its components: Australia's bond market, equity market, housing market and real economy. This result suggests that directional and aggregate volatility spillovers across the entire sample period were, on average, quite small.

3.4.2 Dynamic Analysis of Connectedness

The Australian and global macro-financial system has both evolved and experienced multiple bouts of turbulence from 1987Q1 to 2018Q4. Propelled by advances in technology and globalisation, heightened integration between financial markets and increased capital mobility has been widely documented (see, for instance, Kearney & Lucey, 2004; Kose, Rogoff, Prasad, & Wei, 2003). Movements towards electronic trading and the rising prominence of hedge funds are additional instances of shifts in the paradigms of global finance (Bech, Illes, Lewrick, & Schrimpf, 2016; Moore, Schrimpf, & Sushko, 2016). On the macroeconomic front, the world has witnessed a greater openness to trade and unprecedented alterations in economic policy (Yanikkaya, 2003). Of particular note is the growing prevalence of negative interest rates (Bech & Malkhozov, 2016).

In light of such developments, any single fixed-parameter model is unlikely to provide an optimal assessment of the three-decade sample period that this study covers. While providing a useful summary of 'average' behaviours in volatility spillovers, the preceding static connectedness table fails to embody temporal spillover dynamics. Accordingly, this section focuses on dynamic estimates of Australian macro-financial connectedness. Dynamic analysis allows me to assess whether the magnitudes and structures of spillovers have varied over time, and whether such changes align with particular economic and financial circumstances.

Rolling Window Estimation Approach

To conduct dynamic analysis, I employ a rolling window estimation approach common in related literature (see, for instance, Cotter et al., 2017). In accordance with this approach, the parameters of the VAR model, variance decompositions and Diebold-Yilmaz spillover measures are re-estimated each time the window is rolled forward. As previously, I focus on VAR models of order 4 and generalised variance decompositions of 3-quarter-ahead volatility forecast errors. In order to employ the rolling window approach, a window length must be specified.

Admittedly, the choice of window length necessitates a trade-off between chronicling spillover dynamics and providing a sufficient sample size for accurate estimation of VAR parameters. Larger window sizes simultaneously improve estimate reliability but smooth spillover dynamics (Alter & Beyer, 2014). I select a window length of 32 quarters as it appears to offer a good balance between such trade-offs. Sensitivity of results to alternative rolling window specifications (widths between 24 and 60 quarters) are provided in Sections A.5 and B.6 of Appendix A and B. Connectedness dynamics for both returns and return volatilities are found to be robust in general, despite estimated magnitudes of spillovers tending to decrease with larger sized windows. Robustness is discussed further at the end of this section.

I now proceed to describe dynamics of Australian macro-financial spillovers in terms of total connectedness, total directional connectedness, and pairwise directional connectedness. Summary statistics for all spillover indices are provided in Table 3.4.2 and 3.4.3.

Summary of Total & Net Pairwise Connectedness

Time-segmented summary statistics for the most aggregated (i.e. total) and most disaggregated (i.e. net pairwise) dynamic connectedness measures are provided in Table 3.4.2. Statistics for the full sample period are provided in the top panel, followed by those from three subsample periods — subsample 1 (1995Q1 to 2002Q4), subsample 2 (2003Q1 to 2010Q4) and subsample 3 (2011Q1 to 2018Q4). These subsamples are consistent with those used in Chapter 4's time-segmented regression analyses.

Several general observations may be made from the figures in Table 3.4.2. Starting with the most aggregated measure, the first column indicates that average total connectedness in subsamples 1 and 2 were quite similar (45.964% and 47.057%, respectively). Average total connectedness in subsample 3, however, was recorded at a comparatively lower level at 41.868%. Moreover, subsample 2 differs from subsamples 1 and 3 in the sense that the range of recorded total connectedness was much smaller. Total connectedness deviated within a margin of approximately 17% (i.e. between 40.860% and 57.158%) in subsample 2 relative to the approximate 30% range recorded in subsamples 1 and 3.

Moving on to the net pairwise measures, the Equity Market–Real Economy pair displays the largest absolute average net connectedness over the full sample period (i.e. −1.856%). In this case, the real economy can be interpreted as an overall net 'transmitter' of volatility shocks to the equity market. The Bond Market–Housing Market pair is the second largest net pair in terms of average absolute shock magnitude across the full sample period (i.e. +1.517%). In this case, the housing market is considered a net 'receiver' of volatility shocks from the bond market. It is also worth noting that on average across the full period, the bond market is considered a net 'receiver' of volatility shocks from the equity market (net pairwise connectedness is −1.445%). Interestingly, however, average net spillovers from the equity market to the bond market decrease over the analysed period. This change occurs to the extent that the bond market is considered an average net 'transmitter' in this pairwise relationship by subsample 3 (i.e. +0.299%).

The bond market's transition from a net shock 'receiver' to a net shock 'transmitter' is evident in additional pairwise contexts. For instance, the average net pairwise spillovers in the Bond Market–Housing Market pair increases from −0.629% in subsample 1 to +2.178% in subsample 2, and +3.000% in subsample 3. Similarly, average net pairwise spillovers in the Bond Market–Real Economy pair increase from −2.902% in subsample 1 to +0.872% in subsample 2 and +1.165% in subsample 3.

The equity market is considered an average net shock transmitter in the Equity Market–Housing Market pairwise context over the full sample (i.e. +0.401%). This classification is disproportionately associated with the net pairwise measures recorded in subsample 3. In this subsample, average net pairwise spillovers are recorded at +2.404% compared to subsample 1 and 2's recordings of −0.992% and −0.208%, respectively. The Equity Market–Real Economy net pairwise relationship is comparatively more consistent over the period of analysis. In this case, the equity market is deemed an average net shock receiver with respect to the real economy for every subsample period. Average net pairwise spillovers between the equity market and real economy are recorded at −1.856% over the full sample period. The real economy is also considered an average net shock transmitter in the Housing Market–Real Economy pair, albeit to a lesser extent (−0.074% over the full sample period). Average net spillovers for these two macro-financial segments, however, appear to fluctuate between positive and negative values with no well-defined developments between subsamples. This suggests that the net pairwise relationship between the housing market and real economy is not as definitively pronounced as other net pairwise relations.

Summary of Partial Aggregated Connectedness

Time-segmented summary statistics for the partial aggregated connectedness measures are presented in Table 3.4.3. That is, measures depicting 'net', 'to all' and 'from all' spillovers for a single variable with respect to all others in the system. Statistics are provided for the full sample period and the three previously specified subsample periods.

In terms of spillovers from a given variable 'to all' other variables, several interesting facts emerge. First, the bond market transmits the greatest level of spillovers to the other macro-financial segments, averaging 12.896% on a quarterly basis over the full sample period. This is then followed by the equity market (11.792%), the real economy (10.695%), and finally, the housing market (9.580%). Average volatility shocks from the equity market to all other macro-financial segments are relatively stable across the three subsample periods; values range between 11.349% and 12.050%. Average shocks from the housing market to all others decline from around 11% in subsamples 1 and 2 to approximately 6.5% in subsample 3. The average shocks emerging from the real economy to all other segments fall drastically from approximately 16% in subsample 1 to approximately 8% in subsamples 2 and 3. Finally, as reflected in the earlier net pairwise measures, average shocks transmitted by the bond market to all other segments increased over the full sample period. In subsample 1, average 'to all' shock transmission is recorded at 7.715% before increasing to over 15% in subsamples 2 and 3.

Table 3.4.2
Total & Net Pairwise Connectedness Measures — Volatilities

	TOTAL	BONEQU	BONHOU	BONGDP	EQUHOU	EQUGDP	HOUGDP
FULL SAMPLE							
1995–2018							
Mean	44.963	-1.445	1.517	-0.288	0.401	-1.856	-0.074
Std. Dev.	7.363	2.382	3.570	3.183	3.399	2.648	2.258
Minimum	31.095	-7.139	-6.078	-8.114	-6.565	-11.736	-5.156
Maximum	63.147	3.415	10.763	13.288	6.329	2.499	9.680
SUBSAMPLE 1							
1995–2002							
Mean	45.964	-3.671	-0.629	-2.902	-0.992	-3.093	-0.880
Std. Dev.	9.103	2.028	2.700	2.318	3.186	3.093	1.865
Minimum	31.095	-7.139	-5.557	-8.114	-6.565	-11.736	-4.904
Maximum	61.038	0.505	3.937	0.642	3.899	0.967	5.953
SUBSAMPLE 2							
2003–2010							
Mean	47.057	-0.963	2.178	0.872	-0.208	-0.743	0.397
Std. Dev.	4.000	1.666	3.276	3.399	3.410	1.869	2.434
Minimum	40.860	-5.264	-6.078	-2.305	-6.018	-5.284	-5.156
Maximum	57.158	3.288	9.846	13.288	5.797	2.499	5.004
SUBSAMPLE 3							
2011–2018							
Mean	41.868	0.299	3.000	1.165	2.404	-1.732	0.261
Std. Dev.	6.985	1.379	3.603	1.782	2.561	2.277	2.214
Minimum	32.401	-1.680	-4.715	-2.437	-1.525	-6.829	-2.318
Maximum	63.147	3.415	10.763	5.941	6.329	2.040	9.680

Table presents summary statistics for the total and net pairwise connectedness measures for the sample period of 1995Q1 to 2018Q4 and specified subsamples. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4.

In a similar fashion to the shocks transmitted by the bond market to all other segments, the bond market is also the greatest average receiver of volatility shocks 'from all' others for the full sample period (13.112%). This is followed by the equity market (11.802%), housing market (11.572%), and then the real economy (8.478%). In general, inter-subsample changes in average shocks to a given variable 'from all' others are more stable than their 'to all' counterparts. This is especially the case for the equity market where average shocks 'from all' other variables hover around 12% for all three subsamples. Shocks 'from all' other variables to the real economy fluctuate within an approximate 150-basis point range (i.e. 7.709% to 9.233%), on average, across the subsamples. In a slightly contrasting fashion, average shocks to the bond market 'from all' other segments experience incremental declines from subsample 1 (14.917%) to subsample 2 (13.605%) to subsample 3 (10.815%). Such developments provide additional evidence of the distinct, time-varying spillover dynamics associated with the Australian bond market.

As a synthesis of the 'to all' and 'from all' spillover measures, the 'net' spillover measures allow variables to be classified as net shock 'transmitters' and 'receivers' with respect to the set of all other variables in the system. In terms of absolute magnitude, the real economy reports the largest and only positive reading for average net spillovers over the full sample (+2.218%). The other three variables display negative values, implying that the bond market, equity market, and housing market are net shock 'receivers' from all other segments, on average, over the entire period. These full sample, average net spillover results, however, do not shed light on inter-subsample dynamics.

The inter-subsample changes in net spillover results for the bond market are similar to those observed in the pairwise spillover context. Namely, the bond market's average net spillover results evolve from 'receiver' status in subsample 1 (−7.202%) to 'transmitter' status in subsamples 2 and 3 (+2.087% and +4.465%, respectively). In a comparable manner, albeit to a lesser extent, the equity market's average net spillovers grow from −0.413% in subsample 1 to larger values in subsamples 2 and 3. Conversely, the average net spillover results for the housing market imply that it evolves from a net shock 'transmitter' in subsample 1 (+0.740%) to a 'receiver' in subsamples 2 and 3 (−1.573% and −5.143%, respectively). Finally, the real economy records an average net spillover value of +6.874% in subsample 1, implying an overall net shock transmission role in the system. The definitiveness of this role, however, diminishes in subsamples 2 and 3 where much smaller net results are recorded (−0.526% and +0.305%, respectively).

Table 3.4.3
Partial Aggregated Connectedness Measures — Volatilities

	FULL SAMPLE 1995–2018			**SUBSAMPLE 1 1995–2002**			**SUBSAMPLE 2 2003–2010**			**SUBSAMPLE 3 2011–2018**		
	TO ALL	FROM ALL	NET	TO ALL	FROM ALL	NET	TO ALL	FROM ALL	NET	TO ALL	FROM ALL	NET
MEAN												
Bond Market	12.896	13.112	-0.217	7.715	14.917	-7.202	15.692	13.605	2.087	15.280	10.815	4.465
Equity Market	11.792	11.802	-0.009	11.349	11.762	-0.413	12.050	12.037	0.012	11.979	11.606	0.373
Housing Market	9.580	11.572	-1.992	10.793	10.053	0.740	11.351	12.924	-1.573	6.595	11.738	-5.143
Real Economy	10.695	8.478	2.218	16.108	9.233	6.874	7.964	8.490	-0.526	8.014	7.709	0.305
STD. DEV.												
Bond Market	4.885	3.207	6.150	2.458	2.967	2.429	3.443	1.845	4.461	3.656	3.143	3.417
Equity Market	4.109	3.475	5.022	3.741	5.078	6.758	3.387	2.101	3.430	4.987	2.436	4.234
Housing Market	5.097	3.255	5.395	6.107	2.671	5.163	3.936	1.942	3.989	3.409	4.089	5.211
Real Economy	5.347	2.935	5.464	5.312	2.080	5.175	2.760	3.376	4.571	2.451	2.991	3.006
MINIMUM												
Bond Market	3.103	5.902	-13.207	3.103	7.557	-11.032	5.151	10.511	-13.207	8.787	5.902	-0.585
Equity Market	3.074	3.801	-13.470	4.106	3.801	-13.470	7.136	8.315	-6.882	3.074	6.806	-9.454
Housing Market	2.426	4.274	-17.477	3.101	4.274	-8.007	5.120	8.749	-10.602	2.426	6.168	-17.477
Real Economy	2.024	2.042	-11.892	8.671	4.260	-1.265	2.058	3.413	-11.892	2.024	2.042	-10.836
MAXIMUM												
Bond Market	28.669	19.544	15.581	13.611	19.544	-0.271	24.129	18.358	9.633	28.669	15.005	15.581
Equity Market	21.998	20.465	11.173	17.954	20.465	11.173	19.116	15.697	6.226	21.998	15.694	8.814
Housing Market	23.948	22.438	12.311	23.948	15.199	12.311	18.868	16.261	4.614	15.067	22.438	6.521
Real Economy	26.000	16.791	18.698	26.000	13.762	18.698	12.393	16.791	7.610	12.256	16.249	5.212

Table presents summary statistics for the partial aggregated connectedness measures for the sample period of 1995Q1 to 2018Q4 and specified subsamples. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4.

Visualising Dynamics of Australian Macro-Financial Connectedness

I now graphically present rolling window estimates of the spillover measures to better elucidate time-varying dynamics in Australian macro-financial connectedness. Each chart provides a finer-scale recount of the time-segmented spillover trends introduced in Tables 3.4.2 and 3.4.3.

Dynamics of Total Connectedness

The total spillover index is plotted in Figure 3.4.1. The index signifies the proportion of the total forecast error variance in the Australian macro-financial system that is attributable to shocks across variables. To frame dynamics in the context of underlying macro-financial activity, I provide markings that signify changes in Reserve Bank of Australia (RBA) policy over the period of analysis. A full summary of key macro-financial events over the sample period is provided in Table A.1.1 of Appendix A.

At the commencement of the first window (in 1995Q1 — i.e. 32-quarters after the beginning of the sample in 1987Q1), the index is recorded at 31.832%. The rolling window approach means data from 1987Q1 to 1994Q4 is absorbed in this first estimate. Accordingly, the domestic macro-financial impacts of global events such as the Black Monday Crash in 1987Q3, the U.S. savings and loan crisis of 1989, Iraq's invasion of Kuwait in 1990Q3 and the early 1990s Australian (and global) economic downturn are factored into the 1995Q1 observation. The total connectedness of volatilities in the four-variable system ranged from 31.095% (1996Q1) to 63.147% (2012Q1) over the full sample.

The value of the total spillover index fluctuates considerably, particularly leading up to periods of macro-financial distress. Several cycles in the total spillover index may be noted. The first cycle commences after the burst of the Dot Com Bubble in 2000. The index increases from 31.095% in 1996Q1 to 61.038% by 2002Q3. This appreciation occurs in the form of three small upward cycles that diminish consecutively in terms of oscillation size. The general rise in connectedness between 1996Q1 and 2002Q3 coincides with various noteworthy events. These include the AFC beginning in 1997Q3, the Russian financial crisis and collapse of Long-Term Capital Management (LTCM) in 1998Q3, the Dot Com Crash in 2000, the September 11 attacks and the associated U.S. economic downturn that ensued. The index declines to 40.860% by 2003Q3, before gradually increasing in the lead-up to the GFC to a peak in 2009Q4 (57.158%).

Aggregate spillovers demonstrate significant variability in the years surrounding the 2008–09 GFC. A 4-percentage point rise in the index is recorded between 2007Q3 and 2008Q2, coinciding with the RBA's decision to increase the cash rate target by 100 basis points between August 2007 and March 2008. Monetary tightening during this time increased volatility in domestic bond markets, perhaps explaining elevated shock transmission to other macro-financial segments.

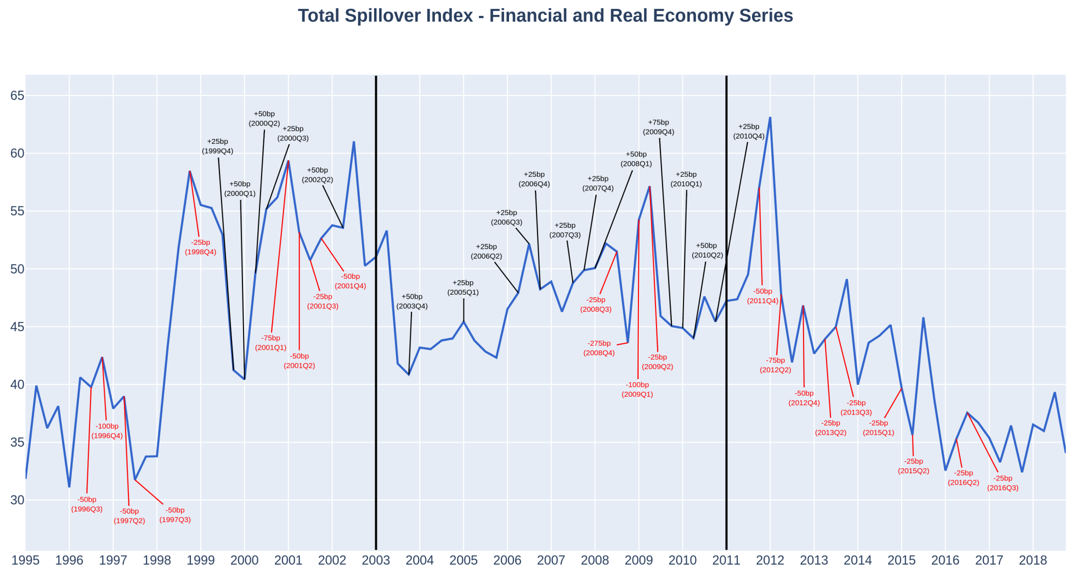

Figure 3.4.1
Total Spillover Index — Volatilities

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. Changes to the cash rate target by the Reserve Bank of Australia (RBA) are marked over the sample period as a reference to macro-financial conditions. Increases in the RBA's cash rate target are marked in black; decreases in the RBA's cash rate target are marked in red. A full recount of key macro-financial events over the sample period is provided in Table A.1.1 of Appendix A.

Total spillovers continued to increase during the GFC. This was especially the case during the credit crunch of mid-July 2007, and financial market turmoil that followed Bear Sterns' takeover and the Federal Reserve's aggressive rate cutting in early 2008. After the bankruptcy of Lehman Brothers in 2008, the global ramifications of the financial crisis intensified as liquidity evaporated internationally. Several other noteworthy events also occurred in neighbouring quarters including American Investment Group's (AIG) bailout, and Fannie Mae and Freddie Mac's placement in conservatorship (2008Q3). Such occurrences and their impact on underlying fundamentals may explain the total spillover index's surge from 43.607% in 2008Q4 to 57.158% by 2009Q2. This period of increasing connectedness coincides with the RBA's drastic 400 basis point reduction in the cash rate target (from 7% to 3%) between September 2008 and April 2009. The 2009Q2 peak coincides with known events including the results announcement from the U.S. Supervisory Capital Assessment Program (SCAP) stress tests.

Total spillovers continued to mount in the years following the GFC, peaking again in 2012Q1 (63.147%). The quarters preceding this peak hosted various turbulent episodes including the European Sovereign Debt Crisis which began in late 2009 and persisted through 2012. 2010Q2 contained the May 2010 flash crash where major U.S. stock indices displayed surges in intraday volatility. 2011Q4 featured perhaps the most noticeable disintegration of economic conditions in Europe, leading to developments including the initial proposal for the Greek economy referendum. Accompanying these far-reaching European events was the ongoing U.S. debt-ceiling crisis that acutely impacted global financial markets in the latter half of 2011.

Following the 2012Q1 peak, the index fell below 50% for the remainder of the sample period. Two post-GFC lows of approximately 32.5% were reached in 2016Q1 and 2017Q4. Total spillovers declined gradually to 34.067% by 2018Q4. These reductions coincide with the quarters most associated the GFC steadily dropping out of the rolling window. Such declines in connectedness may be somewhat attributed to post-crisis changes in macroprudential policy.

The fact that the long-run level of average aggregate spillovers remained broadly steady over the sample period is arguably reassuring for policy-makers. This notion is evidenced by estimated total spillovers being largely similar at the beginning and end of the analysed period. An alternative case where macro-financial volatility spillovers explicitly rose over time may be a cause for concern. Such trends would potentially be interpreted as the rising presence of feedback loops between the financial and real sides of the Australian economy. These loops are reminiscent of those proposed in related theoretical studies such as Bernanke et al. (1996). The lack of long-run trends in aggregate connectedness may be viewed by some as surprising. This is because one may intuitively expect spillovers to increase over time in line with rising market integration. Other studies focusing solely on spillovers in either the financial or real sector of the economy also fail to identify discernible long-run trends (Cotter et al., 2017).

Heightened volatility spillovers between macro-financial segments in the years surrounding the GFC provide evidence of market comovement in the Australian system. Whether such comovement is indicative of contagion — or simply market interdependence — is left to future research (see, for instance, F. Allen & Gale, 2000; Baur, 2012). Similar findings have been acknowledged in other work. This includes Mensi, Boubaker, Al-Yahyaee, and Kang (2017) who document magnified volatility spillovers between European stock markets during periods of crises. Additionally, Cotter et al.'s (2017) study on U.S. macro-financial spillovers chronicles noticeable spikes in aggregate spillovers in May 2009, April 2010 and October 2011. Also of note are Cotter et al.'s accounts of rising connectedness between 2000 to 2002, diminishing connectedness in the post-GFC period, and a lack of explicit long-run trends. Such findings are distinctly similar to those presented in the context of the Australian macro-financial system. Such findings mutually reinforce the integrity of results. These similarities also incite additional research questions including whether dynamics in domestic macro-financial spillovers are globally synchronised.

Dynamics of Partial Aggregated Connectedness — 'To All' Spillovers

While the total spillover index sheds light on aggregate connectedness, it does not elucidate directional dynamics. I now proceed to uncover finer details of spillover structures via partial aggregated analysis. Figure 3.4.2 visualises dynamic estimates of directional volatility spillovers from each variable to all other variables. It is immediately clear that spillovers originating from each variable fluctuate distinctly over time.

Volatility shocks transmitted from the bond market to all other variables vary significantly but tend to increase over the sample period. In 1995Q1 spillovers are recorded at 4.230% but quickly rise to 10.568% by 1995Q4. Spillover transmission decreases to around 6% in the years most associated with the AFC (1997 to 1998). The bond market then exhibits increasing transmission of shocks to other macro-financial segments. Three rapid bursts in transmission lead to successive peaks of 9.725% (1999Q3), 13.612% (2001Q4), and 17.301% (2003Q3). Spillover levels during subsample 2 remain generally higher than those recorded in subsample 1, with another peak being reached in 2006Q3 (24.129%). The metric slightly decreases during 2008 before showing substantial growth in the period during, and following, the GFC. Shocks from the bond market to all other variables increase from 10.598% in 2008Q4 to a full sample maximum of 28.669% in 2012Q1. After this peak, spillovers return to levels broadly similar to those recording during the majority of subsample 2. Between 2013Q1 and 2018Q4, bond market spillovers to all other variables mostly fluctuate between 12% and 16%.

Unlike the bond market, shocks from the equity market to all other variables display no apparent long-run trends. In saying this, these spillovers demonstrate dips and spikes of much larger magnitude relative to the case of the bond market. Between 1995Q3 and 1996Q2, equity market shock transmission rose from 6.164% to 17.502%. Spillovers then decrease in the ensuing quarters to 4.106% by 1999Q3. Between 1999Q3 and 2001Q1 the metric rises again to 12.122%, before dipping to another low of 6.538% in 2001Q3. Another oscillatory movement occurs in the quarters towards the end of subsample 1, with the metric again peaking in 2003Q1 at 18.097%. For the majority of subsample 2, spillovers hover between 8% and 11%, before surging in the quarters near the GFC. Shocks from the equity market to all other variables increase from 7.490% to 17.287% between 2008Q4 and 2009Q1, before rising to a full sample maximum of 22.000% in 2012Q1. Spillovers are then recognised to cyclically decrease in the following three years, reaching a full sample minimum in 2015Q4 (3.074%). Shock transmission from the equity market to all others appears to increase in the final three years of the period, gradually increasing to around 10% by 2018Q4.

Of key note is the fact that dynamic spillover estimates from the bond and equity markets to all others tend to peak above average values during times of substantial market turbulence. This is not necessarily the case for the housing market and real economy.

Dynamic spillover estimates from the housing market to all other variables range from approximately 3% to 6% in both the first and last three years of the sample. Despite the apparent lack of long-run trends, several short- and medium-run fluctuations are evident. These fluctuations may be broken into five cycles. The first cycle begins with a surge from 3.308% in 1998Q1 to 21.718% in 1999Q3. Estimates then proceed to fall to around 11% in the next two years. The second cycle commences in 2001Q3 where an estimate of 6.510% is recorded prior to another rapid increase towards a full sample maximum of 23.948% in 2002Q3. Shocks from the housing market to all others then rapidly decline to 5.120% by 2003Q4, before commencing a gradual, four-year appreciation to 18.513% in 2008Q1. As the quarters embodying the GFC enter the rolling window, spillovers decline from this peak in 2008Q1 to a low of 3.555% in 2011Q3, marking the end of the third cycle. The final two cycles are comparatively shorter, occurring from 2011Q3 to 2014Q3 (4.669%) (with a peak of 12.600% in 2014Q4), and 2014Q3 to 2017Q1 (2.812%) (with a peak of 15.067% in 2015Q4).

Similar to the case of the bond market, levels of spillovers transmitted by the real economy to all other variables change dramatically after 2002Q4. These spillovers are estimated at 14.989% in 1995Q1, before increasing to 19.944% in 1995Q2. Shock transmission then decreases in magnitude, fluctuating between 9.907% and 12.844% in 1996 and 1997. Spillovers from the real economy to all other variables then surge in two instances. The first occurs between 1997Q3 and 1998Q4 where estimates rise from 9.907% to 24.395%. The second occurs between 2000Q1 (13.414%) and 2001Q3 (26.000%); the latter quarter hosts the largest spillover estimate for the full sample period. Following this peak, estimates then drop below 10% for the majority of the remaining quarters. Spillover estimates fall even lower during 2010 and 2011, with a full sample minimum of 2.024% occurring in 2011Q1. Spillovers generally trend upward from this point onwards, although do not return to the comparatively higher levels recorded in subsample 1.

The fall in the magnitudes of spillovers transmitted from the real economy to other variables after 2002Q4 may be attributed to quarters containing key economic events being rolled out of the estimation window. As a 32-quarter rolling window approach is employed, *to all other* spillover estimates from 1995Q1 to 2002Q1 stem from a pool of data from 1987Q1 to 2001Q4. Once spillovers transmitted from the real economy to all others are estimated in 2002Q1, data between 1987Q1 and 1993Q4 is rolled out of the window. This includes real economic data directly impacted by events including the U.S. savings and loan crisis (1989), Kuwait's invasion by Iraq (1990) and the early 1990s Australian recession. With this in mind, the dramatic fall in spillovers transmitted by the real economy is less surprising. Despite this fall, the real side of the domestic economy can, at the very least, be seen to play some role in shock transmission over the remaining period of analysis. This is opposed to spillovers solely originating from the financial side of the economy. Implicitly, this means macro-financial spillovers are bidirectional in nature. Such evidence may be interpreted as preliminary support for the presence of feedback loops between the two segments of the Australian macro-financial system as predicted by theories involving the financial accelerator (see Bernanke et al., 1996).

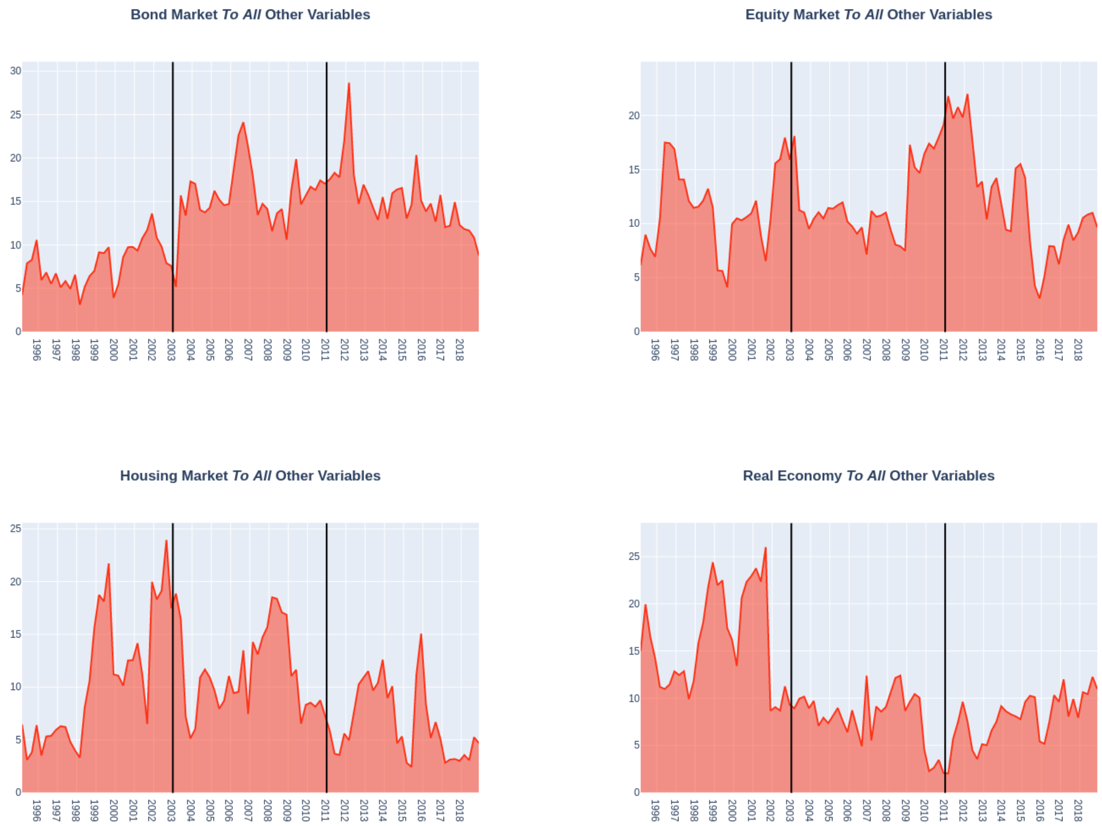

Figure 3.4.2
Spillovers *To All* Variables — Volatilities

Figure plots the spillovers transmitted by each variable to all others for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. A full recount of key macro-financial events over the sample period is provided in Table A.1.1 of Appendix A.

Dynamics of Partial Aggregated Connectedness — 'From All' Spillovers

Figure 3.4.3 visualises dynamic estimates of directional volatility spillovers to each single variable from all other variables. While significant short- and medium-run fluctuations in these estimates exist, definitive trends are less evident. Of note is the downward trend in spillovers to the bond market from all other variables in subsample 3. Over the course of subsample 1, spillovers from all other variables to the bond market increase from 7.557% in 1995Q1 to a peak of 19.544% in 2001Q1. As per Figure 3.4.2, this rise in the general level of shocks received by the bond market may be traced back to corresponding increases in *'to all others'* shock transmission by the housing market and real economy between 1995Q1 and 2002Q4. The magnitudes of shocks received by the bond market from all others are typically smaller in subsample 2 relative to subsample 1. Spillovers rise at the onset of the GFC; most noticeable is the jump from 12.920% in 2007Q2 to a subsample peak of 17.985% in 2008Q3. While spillovers hover between 13% and 14% at the beginning of subsample 3, levels fall significantly once quarters most associated with the GFC are rolled out of the sample. For instance, consider the period between 2014Q4 and 2015Q4. This time frame corresponds to data from 2008Q4 to 2009Q4 dropping out of the rolling window. In this time, spillovers from all other variables to the bond market fall from approximately 14.5% to 7%. Moreover, the lowest result for the full sample period occurs late in subsample 3; spillovers fall below 6% in 2017Q3.

Akin to the increase in shocks received by the bond market during subsample 1, the equity market records increased volatility spillovers from all other variables between 1995Q1 and 2002Q4. Such increases are of greater intensity compared to the bond market, as typified in the movement from 3.801% in 1995Q4 to a peak of 20.009% in 2001Q3. This peak coincides with the September 11 attacks. Shocks received by the equity market from all other variables gradually decline over the following two years, reaching a low of 8.576% in 2004Q4. Spillovers then hover at levels between 10% and 15% until halfway through subsample 3. Spillovers proceed to fall from 15.694% in 2015Q1 to 6.806% in 2015Q4, before settling around 8.5% by 2018Q4. Similar to the bond market, the sharp drop in spillovers from all other variables to the equity market occurs in accordance with quarters most associated with the GFC rolling out of the sample.

Spillovers received by the housing market and real economy from all others appear less stable than those recorded for the bond and equity markets. These spillovers with respect to the housing market range between 5.004% (1996Q1) and 15.199% (2002Q4) in subsample 1. Similar large-scale variations in estimates occur in subsample 2 where a low of 8.749% (2006Q1) and high of 20.933% (2011Q4) is recorded. While spillovers from all others to the housing market clearly increase during periods of rising turbulence (i.e. the 1997 AFC, the 2001 Dot Com Bubble and the 2008–09 GFC), mounting shocks are greatest in the two years preceding the full sample peak in 2012Q1 (22.438%). This peak coincides with the recorded peaks of spillovers transmitted to all other variables from the bond market and equity market in Figure 3.4.2. Partial aggregated spillovers received by the housing market subsequently fall to approximately 9% by 2016Q1 before settling around 10% in 2018Q4.

Spillovers received by the real economy from all other variables peak in subsample 1 at 13.762% (1999Q3). The second largest subsample result occurs in 2002Q3 (12.515%). These two peaks coincide with the largest recorded quarters of shock transmission from the housing market to all other variables. This suggests that the primary driver behind heightened shocks to the real economy in these quarters was shock transmission from the housing market. Partial aggregated spillovers received by the real economy increase drastically between 2003Q4 (3.413%) and 2006Q3 (16.791%). During these periods, rising shock transmission from the bond and housing markets to all other variables is observable. Spillovers received by the real economy also rise rapidly in the midst of the GFC — from 4.660% in 2008Q2 to 14.220% in 2009Q2. In this instance, shocks appear to stem mainly from the equity and housing markets. Two more noticeable peaks in spillovers are identified in subsample 3: these occur in 2012Q1 (13.006%) and 2015Q4 (16.249%). The 2012Q1 peak appears to be most associated with shocks transmitted from the bond market, given their elevation from 17.548% in 2011Q1 to 28.669% in 2012Q1. The second peak appears most associated with shocks originating in the housing market: these increased from 2.882% to 15.067% on a 'to all' basis over 2015. Shocks received by the real economy from all other variables recorded a gradual rise in the final two years of the sample, rising from 6.782% (2017Q1) to 11.109% (2018Q3).

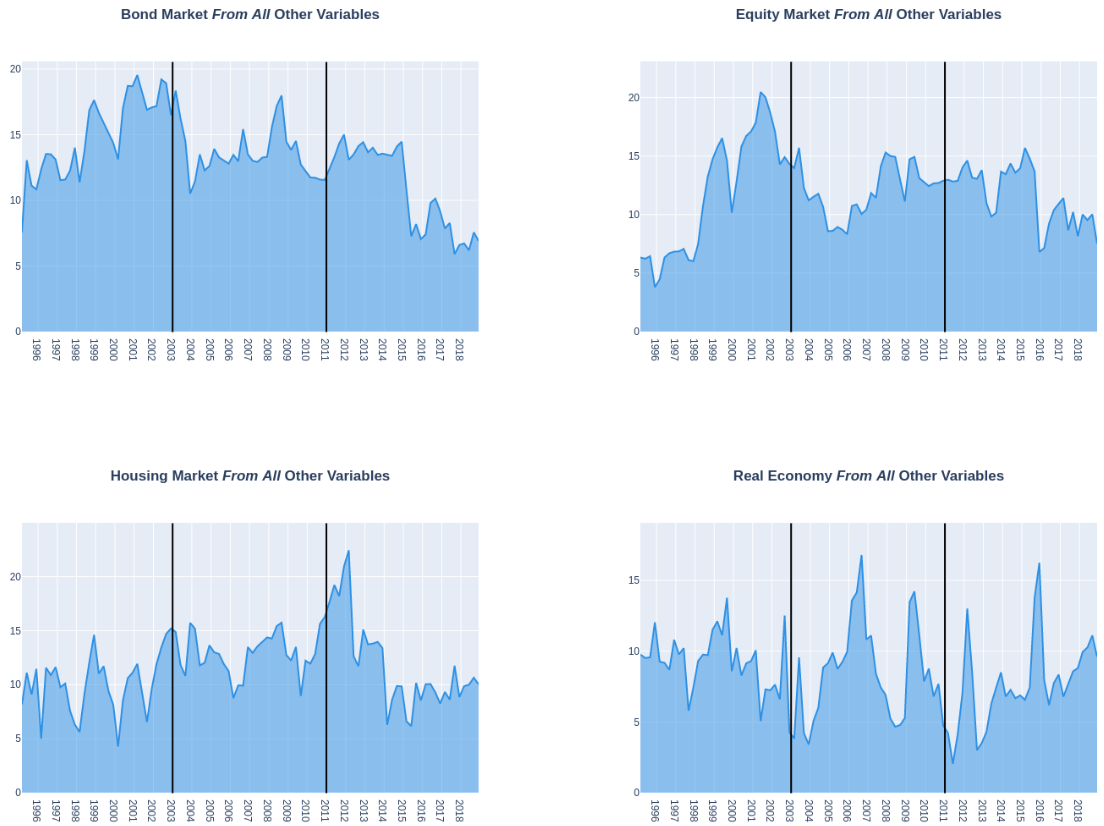

Figure 3.4.3
Spillovers *From All* Variables — Volatilities

Figure plots the spillovers received by each variable from all others for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. A full recount of key macro-financial events over the sample period is provided in Table A.1.1 of Appendix A.

Dynamics of Partial Aggregated Connectedness — 'Net' Spillovers

Figure 3.4.4 plots dynamic results for net directional volatility spillovers for each variable. These are rolling estimates of the difference between shocks transmitted from a given variable *'to all'* other variables and the shocks received by a given variable *'from all'* others. Evidently, the 'net' spillover status of each variable alternates between 'net transmitter' (i.e. positive values) and 'net receiver' (i.e. negative values) depending on the quarter considered. This provides prime evidence of the time-varying nature of Australian macro-financial connectedness. In this case, 'greater' values of net spillovers correspond to estimates diverging further from zero; that is, in either positive or negative direction. This point is worth noting as larger net values do not necessarily correspond to conventionally larger values (i.e. larger than zero).

The most striking observation in terms of the bond market's net spillover status is its transition from net receiver to net transmitter after 2003Q1. Between 1995Q1 and 2003Q1, net bond market shocks moved from −3.319% to −13.207%. Following 2003Q1, however, the bond market generally became a net transmitter of shocks in the system for the remaining quarters. The first surge in the bond market's status occurred in 2003 when net spillovers grew from −13.207% (2003Q1) to +6.791% (2003Q4). This surge is traceable to spillovers from the bond market to all others over this period growing (5.151% to 17.301%), while spillovers from the equity and housing markets to all others simultaneously shrunk (18.097% to 9.508%, and 18.097% to 9.508%, respectively). Spillovers to the bond market from all others fell from 18.358% (2003Q1) to 1.511% (2003Q4) as a consequence. The second surge occurred between 2005Q3 and 2006Q2 where net bond market spillovers rose from +1.555% to +9.632%. Over this period, shocks to all others from the bond market increased (14.562% to 22.611%), while shocks from all others to the bond market decreased (13.006% to 12.979%). The latter movement may largely be attributed to a reduction in shocks transmitted from the equity market to all others (i.e. 11.959% to 9.065%) over the same time frame.

Following these two surges, net bond market spillovers experienced a brief period of 'receiver' status where spillovers hovered around −4% in 2008. This period is likely attributable to the burst in shock transmission from the equity and housing markets at the beginning of the GFC. After this brief period, however, net spillovers returned to broadly positive territory for the sample's remaining quarters. Net bond market spillovers peak at +15.581% in 2012Q1 coinciding with the RBA's decision to lower the cash rate target in November 2011 for the first time since the GFC. Between November 2011 and June 2012, the RBA cut rates by 125 basis points. Net bond market spillovers display another noticeable peak in 2015Q3 (+12.158%). This result is preceded by a simultaneous increase in spillovers from the bond market to all other variables (12.992% to 20.336%) and decrease in spillovers from the equity market to all other variables (9.433% to 4.230%) from 2014Q1 to 2015Q3.

Contrary to the bond market's transitioning net spillover status, the equity market's results are better described by time-varying oscillation. In the first half of subsample 1, the equity market is classified as a net transmitter of spillovers with a peak at +11.173% in 1996Q2. In the second half of this subsample, net spillovers are generally negative, experiencing two major lows in 1999Q2 (−10.906%) and 2001Q3 (−13.471%). The first of these lows is traceable to the decline in shocks transmitted from the equity market to all others (13.222% to 5.617%) coupled with the rise in shocks transmitted to the equity market from all others (13.242% to 16.524%) between 1998Q3 and 1999Q2. Over the course of subsample 2, net equity market spillovers fluctuate between negative and positive values. These fluctuations, however, are not as great in magnitude relative to those recorded in subsamples 1 and 3. Of key note is the equity market's growing status as a net shock receiver in the quarters preceding the GFC. Net equity market spillovers move from −0.805% in 2007Q2 to −6.882% in 2008Q2, largely due to surging shock transmission by the housing market and real economy over the same period. Once the macro-financial system embodies the principal effects of the GFC, net equity market spillovers once again enter positive territory: a peak of +8.814% is reached in 2011Q1. Afterwards, however, the equity market becomes a net receiver of shocks for the most part of 2013 through to 2017. These years are explained by a fall in shocks from the equity market to all others, relative to the rise in shocks received from the other macro-financial segments. By 2018Q4, net equity market spillovers hover around +1% — a net result less definitive than other quarters in the sample period.

Similar to the time-varying oscillations displayed by the equity market, the net status of the housing market deviates over the sample period. Between 1995Q1 and 1998Q3, shocks received by the housing market exceed the shocks transmitted by the housing market with respect to all other variables. This net shock receiver status dissipates as of 1998Q4 after which the housing market begins a five-year period of net shock transmission. The magnitude of net shock transmission spikes in 1999Q3 (+12.310%) and again in 2001Q4 (+10.350%). The housing market re-enters the realm of negative net spillovers in 2004, where net spillovers reach a distinctive low of −10.602% (2003Q4). The advancement towards this low is attributable to the decrease in spillovers from the housing market to all other variables between 2003Q2 and 2003Q4 (16.442% to 5.120%). From 2004Q1 to 2008Q4, net housing market spillovers fluctuate around the 0% baseline, reflecting a less definitive period of net spillover classification. Once the rolling window incorporates the quarters most associated with the GFC, the housing market exhibits an extended period of net shock absorption. The extent of this net receiver status is greatest in 2012Q1 when net housing market spillovers are recorded at −17.477%. For the remainder of the sample period, the housing market is generally a net receiver of shocks, but net magnitudes are smaller than in the quarters prior. Between 2013Q1 and 2018Q4, net housing market spillovers generally persist around −4%, with a notable high (+6.521%) and low (−8.579%) in 2014Q4 and 2017Q3, respectively.

Net spillovers for the real economy transition from a definitive net transmitter period between 1995Q1 and 2004Q2, to one characterised by time-varying undulation. Interestingly, this is in contrast to what has been found in the U.S. macro-financial system. Cotter et al. (2017) classify the U.S. real economy (represented by industrial production) as a net receiver of spillovers from January 1980 to September 2015. A potential catalyst for this result was their incorporation of financial data at a higher frequency relative to the quarterly frequency employed in this study. Alternatively, the Australian real economy may simply embody more of a relative shock-transmitting role within its associated macro-financial system compared to that of the U.S. real economy.

Net spillovers for the Australian real economy gradually increase during subsample 1, reaching highs in 1998Q4 (+12.885%) and 2001Q3 (+18.700%). Over this subsample, shocks emerging from the real economy were sizeable, largely due to events including the AFC, the introduction of the GST, and the September 11 attacks. From 2001Q4, the magnitudes of net real economy spillovers are smaller in absolute terms relative to preceding quarters. Net spillovers reach their full sample low in 2006Q3 (−11.892%). This low point corresponds with a high point in terms of net bond market shock transmission. The real economy's net spillovers then proceed to increase to a peak of +7.610% in 2008Q3, reflecting the conditions associated with the GFC. This peak also mirrors a period of net shock absorption by the bond and equity markets. The real economy is then classified as a net shock receiver between 2009Q1 and 2011Q1, before generally holding a net transmitter role until the end of the sample period. The most notable subversion of this status occurs in 2015 when net spillovers move from +2.019% (2015Q1) to −10.836% (2015Q4). This movement coincides with a substantial increase in spillovers transmitted by the housing market to all other segments, rising from 2.822% to 15.067% over the same period.

Figure 3.4.4
Net Spillovers for Variables — Volatilities

Figure plots the net spillovers for each variable to/from all others for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. A full recount of key macro-financial events over the sample period is provided in Table A.1.1 of Appendix A.

Dynamics of Net Pairwise Connectedness

Figure 3.4.5 visualises the net spillover relationships between pairs of variables for the full sample period. The charts provide additional insight into the drivers of fluctuations in the previously discussed partial aggregated measures. Recall that net pairwise spillovers need only be provided in one direction to capture spillovers between a given set of variables. For instance, the value of net pairwise spillovers from the bond market to the equity market is equivalent to minus one times the net pairwise spillovers from the equity market to the bond market.

Starting with the Bond Market–Equity Market pair, several points can be made. First, the equity market held the dominant shock transmission role between 1995Q1 and 2007Q4. This is signified by the negative values of the measure, depicting the fact that shocks transmitted from the equity market to the bond market exceeded shocks transmitted from the bond market to the equity market. This net spillover characterisation is also reflected in the U.S. context over the same period, with the U.S. equity market found to be a net transmitter of shocks to the bond market between 1999 and 2002 (Cotter et al., 2017).

The equity market's net transmitter role is reduced, and even reversed, in multiple instances during the latter half of the sample period. Of key note is the period between 2008Q2 and 2009Q3 where the bond market held the dominant role in net spillover transmission. The bond market also displays net transmitter status between 2010Q2 and 2011Q4. The dissipation of the equity market's explicit role as net pairwise shock transmitter supports earlier findings regarding the rising prominence of bond market shock transmission over the sample.

The bond market's elevated role as a shock transmitter in the latter fragments of the sample is reaffirmed by the Bond Market–Housing Market pairwise dynamics. While the bond market switches from a net transmitter to net receiver role on two occasions in subsample 1, it generally remains a net shock transmitter for all other quarters. The extent of the bond market's net spillover transmission to the housing market first peaks in 2003Q4 (+9.846%) and then again in 2012Q1 (+10.763%). The quarters preceding both peaks involved more active policy stances from the RBA, with the cash rate target rising and falling 50 basis points between November and December 2003 and November and December 2011, respectively. During subsamples 2 and 3, the housing market once again becomes the net pairwise shock transmitter. This occurs throughout 2008 and from 2013Q1 to 2014Q4. The 2008 episode may be linked to the deteriorating sentiment surrounding property investment that occurred in the early stages of the GFC (see Chapter 4). The latter episode coincides with the RBA's extended period of passive monetary policy whereby the cash rate remained at 2.5% for 15 consecutive meetings. The bond market reclaims its role as net pairwise shock transmitter in its relationship with the housing market from 2015Q1 until the sample's end.

The rising prominence of the bond market in terms of shock transmission is reiterated in the Bond Market–Real Economy net pairwise chart. Between 1995Q1 and 2004Q1 the bond market is primarily a net receiver of spillovers from the real economy. This occurs to the greatest extent in 2001Q2 (−8.114%). The real economy's net spillover dominance is distinctively overthrown in the quarters preceding the GFC, most notably from 2004Q2 to 2007Q1. Spillovers from the bond market to the real economy exceed the spillovers from the real economy to the bond market during this time. Similar dynamics in pre-GFC spillover structures are also found between the U.S. bond market and U.S. real economy (Cotter et al., 2017). The Australian net pairwise metric reaches its full sample maximum in 2006Q2 (+9.107%). For remaining quarters, the bond market generally maintains its net transmitter status. An exception to this fact occurs from 2007Q2 to 2009Q1 where net pairwise spillovers fall below zero. This signifies the real economy's dominant shock transmission role in the midst of the GFC. Two additional, smaller peaks in the measure are also noticeable: these arise in 2012Q1 (+4.795%) and 2015Q3 (+5.941%). Such surges in net shock transmission from the bond market are not surprising given their simultaneous presence in the Bond Market–Housing Market pairwise dynamics.

Elevated shock transmission from the bond market to other variables over time may be attributed to known macro-financial conditions in the latter parts of the sample. This includes, for example, the emergence of the European Sovereign Debt Crisis in 2009 as well as heightened RBA activity and unprecedentedly low domestic interest rate targets. Potential determinants of the dynamics of Australian macro-financial connectedness are explored in Chapter 4.

Compared to the three previously discussed pairwise relationships, the Equity Market–Housing Market net spillover measure displays comparatively slower oscillation. Between 1995Q1 and 1998Q4, the equity market generally holds the dominant pairwise role, before the housing market becomes the net pairwise transmitter from 1999Q1 through 2002Q4. Following a brief period of equity market dominance at the commencement of subsample 2, the housing market exhibits more prominent relative shock transmission from 2005Q4 to 2009Q4. The extent of the housing market's net transmitter role peaks in 2007Q4 (−6.018%). Upon the inclusion of GFC-affiliated quarters within the rolling window, the Equity Market–Housing Market measure returns to positive territory: this is the case from 2009Q1 and 2015Q2. For the remaining 14 quarters to 2018Q4, results mainly fluctuate between −1% and +1%, with housing market net shock dominance being most common.

The Equity Market–Real Economy net pairwise chart features more definitive relationships than seen previously. The real economy is undoubtedly the net shock transmitter in the majority of quarters within the sample period. The most obvious anomaly to this fact occurs throughout 2007: the equity market is the net shock transmitter in all quarters, peaking at +2.499% in 2007Q1. Comparatively, instances where the real economy dominates the equity market in volatility spillover transmission are much larger in scale. Of particular note are the spikes in 1999Q2 (−7.500%), 2001Q3 (−11.736%) and 2015Q3 (−6.829%). Towards the end of subsample 3, however, the equity market appears to return to net pairwise dominance, with estimates hovering around +1% in the sample's final 5 quarters. These results for the domestic Equity Market–Real Economy pair diverge from those obtained for the U.S. macro-financial system. Cotter et al. (2017) find that U.S. industrial production is almost always a net shock receiver from the equity market between 1980 and 2015. As mentioned earlier, these differing results may stem from the inherently unique status of each macro-financial system.

The final plot presents dynamics for the Housing Market–Real Economy net pairwise metric. For the majority of subsample 1, the real economy is firmly established as the net shock transmitter in this pairwise context. This notion is consistent with the role of the real economy in its net pairwise relationships with the bond and equity markets. Net spillovers rarely exceed −2% during these early observations. Prior to the commencement of subsample 2, the housing market exhibits net pairwise dominance with the measure reaching +5.953% in 2002Q3. The housing market's authority gradually declines in the ensuing quarters, with the real economy again dominating in the quarters preceding the GFC. Two noticeable spikes in the metric occur around this time, namely in 2006Q4 (−5.156%) and 2008Q2 (−3.703%). Following 2009Q4, the housing market displays greater relative shock transmission for the majority of quarters until 2017Q1. Peaks in housing market dominance are recorded in 2010Q1 (+5.004%) and 2015Q4 (+9.680%). The latter of these peaks is somewhat discernible in the Equity Market–Housing Market pairwise relationship with a distinct movement towards negative territory observable during 2015. Housing Market–Real Economy net pairwise spillovers then fluctuate between −0.622% (2017Q4) and −2.318% (2018Q4) in the final 8 quarters of the sample. This yet again re-establishes the real economy's status as a net shock transmitter in this pairwise context.

Preceding net pairwise analyses allowed for the evaluation of whether common shocks had idiosyncratic impacts on the various macro-financial segments. As per the results for the Bond Market–Real Economy, Equity Market–Real Economy and Housing Market–Real Economy measures, it is clear that spillover structures between the real sector and assorted financial markets differed over the sample period. Uncovering idiosyncratic financial market responses to common macroeconomic shocks aligns with results from other studies. Brenner et al. (2009), for instance, document diverging reactions (both in timing and magnitude) by the U.S. bond and equity markets to macroeconomic news announcements.

Moreover, the magnitudes and structures of spillovers received by the Australian real economy clearly depended on the specific source of shocks. That is, whether spillovers stemmed from the bond market, equity market or housing market. The culmination of the six charts comprising Figure 3.4.5 provide support for not only the time-varying nature of spillover magnitudes, but also the time-varying nature of spillover structures. That is, the ways in which pairwise volatility spillovers within the Australian macro-financial system fluctuate and evolve over time.

Figure 3.4.5
Net Pairwise Spillovers Between Variables — Volatilities

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The figures only display net pairwise spillovers in one direction for any given pair of variables. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. A full recount of key macro-financial events over the sample period is provided in Table A.1.1 of Appendix A.

Robustness of Results

The dynamics of all spillover metrics are generally preserved and remain robust to changes in econometric specifications. Although qualitative patterns of connectedness are similar, some variations in magnitude are noticeable in robustness checks. This is the case for spillover estimates stemming from both raw rates (Appendix B) and volatilities (Appendix A) of return and growth. Such variations are not necessarily problematic as this study focuses on exploring dynamics. As cycles, developments and trends are found to be broadly robust, central findings remain largely unaffected.

Sensitivity of results to changes in VAR ordering are provided in Sections A.3 and B.4 of Appendix A and B. VAR models with 2 to 5 lags were tested while using the previous specifications of a 32-quarter rolling window and 3-quarter forecast horizon. Lag lengths greater than 5 are not examined as such models markedly increase the number of parameters to be estimated, thereby reducing the degrees of freedom during rolling window estimation (Fong, Li, & Sze, 2016).

The magnitudes of estimated connectedness tend to increase when employing a larger number of lags in the VAR models used to derive spillover metrics. The dynamics discussed earlier are accentuated when 5 lags are incorporated, whereas dynamics appear less pronounced in the instances of using 2 and 3 lags. As such, the plots associated with VAR models of higher order can be considered *smoother* relative to those produced using VAR models with fewer lags. The reason for this is intuitive; more lags leads to a greater sized estimation window (Alter & Beyer, 2014).

Sensitivity of results to changes in forecast horizon are provided in Sections A.4 and B.5 of Appendix A and B. Forecast horizons from 2 to 5 quarters are tested, while using the previous specifications of a 32-quarter rolling window and VAR models of order 4.

Magnitudes of estimated connectedness tend to rise when using a larger forecast horizon during spillover estimation. This means that the levels of connectedness identified earlier tend to enlarge when forecast horizons of 4 and 5 quarters are used. When the forecast horizon is reduced from 3 to 2 quarters, connectedness dynamics become relatively less pronounced. These observations are consistent with other studies (see, for instance, Han et al., 2017; Maghyereh, Awartani, & Hilu, 2015). Such results are not surprising; larger forecast horizons have a greater chance of capturing system interdependencies. This is because potential spillovers that only occur in periods further into the future enter the forecasting horizon. Accordingly, there is no reason for spillover magnitudes to be robust to alternative forecast horizons (Diebold & Yilmaz, 2014).

It may also be noted that unit increases in spillover magnitudes appear to decline with additional unit increases in the forecast horizon. That is, for instance, the rise in total connectedness when moving from a 2-quarter to 3-quarter forecast horizon is greater than the rise in total connectedness when moving from a 3-quarter to 4-quarter forecast horizon.

Sensitivity of results to changes in rolling window length are provided in Sections A.5 and B.6 of Appendix A and B. Window sizes between 24 and 60 quarters are considered while simultaneously using the previous specifications of a 3-quarter forecast horizon and VAR models of order 4.

When using larger rolling estimation windows, computed magnitudes of spillovers fall. As expected, connectedness dynamics appear smoother when larger rolling windows are employed. This is due to the fact that more observations are included in windows of larger size. Generally, the reduced smoothing of relatively shorter rolling windows allows volatility dynamics to be observed with greater resolution. Similar to the sensitivity analyses conducted for various forecast horizons, the unit decreases in connectedness magnitudes fall with additional unit increases in rolling window size. For instance, the fall in total connectedness when moving from a 24-quarter to 28-quarter rolling window is greater than the fall in total connectedness when moving from a 28-quarter to 32-quarter rolling window.

3.5 Key Findings: Dynamics of Australian Macro-Financial Connectedness

The results documented and discussed in Section 3.4.2 provide evidence of the time-varying nature of Australian macro-financial connectedness. Where appropriate, I also provide contextualisation of domestic estimates via reference to Cotter et al.'s (2017) U.S. study. While results are described thoroughly for the purpose of rigour, 10 key findings may be presented to better summarise the most crucial dynamics of historical connectedness.

1. Distinct short- and medium-run fluctuations were observed in the magnitudes and structures of connectedness over the sample period. These fluctuations were generally more prevalent than definitive, long-run trends.

2. Variations in the estimates of the computed spillover metrics coincided with known macro-financial events and conditions.

3. Levels of aggregate macro-financial connectedness tended to rise in periods leading up to crises.

4. The bond market became a more prominent transmitter of volatility spillovers from 2003Q1 onwards.

5. The equity market demonstrated significantly greater levels of shock transmission in the quarters immediately following the GFC.

6. The housing market's role as a net shock transmitter gradually diminished around the time of the GFC for the remainder of the sample period.

7. The real economy's role as a net shock transmitter diminished drastically after 2002Q4.

8. The historical net spillover relationships between the Bond Market–Housing Market, Equity Market–Housing Market and Housing Market–Real Economy pairs were relatively oscillatory in nature.

9. In the Bond Market–Real Economy net pairwise relationship, the real economy was the dominant net shock transmitter before 2002Q1, while the bond market exhibited dominance in the years following.

10. In the Equity Market–Real Economy net pairwise relationship, the real economy generally displayed dominance in net shock transmission over the full sample period.

Supplementary Results: Return & Growth Rates

Primary analysis focused on spillovers in *volatilities* rather than raw *rates* of return and growth. This focus is consistent with existing literature on macro-financial linkages and financial spillovers in general. Focusing on volatility is justified based on its interest to a variety of stakeholders, including those concerned with gauging risk and pricing financial instruments.

With this being said, Appendix B presents all estimates for static and dynamic spillovers conducted using raw rates of return and growth. Rates of return were used for all financial variables, while rates of growth were used for GDP (i.e. the 'real economic' variable). While results are not discussed in detail for the purpose of conciseness, key findings remain consistent with those already identified. Of the differences that exist, many may be attributed to the fact that rates of return and growth can be either positive or negative by construction. This is opposed to the previously used volatility data that is always weakly positive.

Of note is the fact that both sets of results feature rising aggregate connectedness in quarters leading up to crises. As per Figure B.3.1, the total spillover index drastically rises in quarters preceding the burst of the Dot Com Bubble and the GFC. The index drastically falls in the quarters where GFC-affiliated data is rolled out of the estimation window.

Various sentiments are also echoed from previous discussion in terms of partial aggregated measures. Of note is the fact that the bond market's net shock transmission role grows in the quarters surrounding the GFC. The equity market's role appears oscillatory, whereas the real economy demonstrates a clear transition from net shock transmitter to net shock receiver after 2003Q4. The housing market is also noted as a net receiver of shocks for the majority of the sample period.

Many key findings also appear consistent in the context of net pairwise analysis. This is particularly the case when assessing the bond market's linkages with other macro-financial segments. In its pairwise relation with the equity market, a surge in bond market net shock transmission is particularly evident around the time of the GFC. This is also the case with respect to the real economy in periods coinciding with elevated RBA activity, most noticeably during the 2006 to 2008 hiking of the cash rate. The bond market also demonstrates consistent pairwise net shock dominance in its relation with the housing market in both sets of results.

Chapter 4
Determinants of Macro-Financial Connectedness

In the previous chapter, I documented historical dynamics of Australian macro-financial connectedness from 1995Q1 to 2018Q4. I showed that substantial time-variation existed in the estimated magnitudes and structures of assorted spillover measures. Estimates appeared to exhibit varying degrees of fluctuation in the short- and medium-run to a greater extent than distinct, long-run trends. Fluctuations appeared to coincide with known events and conditions relevant to the Australian macro-financial system.

Motivated by these findings, I now examine whether certain factors explain temporal dynamics of connectedness more than others. I also aim to determine whether the previously computed spillover measures are inherently related to underlying macro-financial phenomena. To do so, I estimate the predictive abilities of a set of macroeconomic (hereafter, "macro") and financial variables in the context of time-varying connectedness estimates. Again, I focus on estimates derived from return and growth volatilities. Appendix C presents all regression results using spillover metrics derived from raw rates of return and growth.

4.1 Empirical Strategy

Consistent with related studies, I conduct explanatory analysis using time-segmented, ordinary least squares (OLS) techniques (see, for instance, Cotter et al., 2017). Subsequent regression analysis is completed for the full period of obtained spillover results (1995Q1 to 2018Q4), as well as three subsample periods: subsample 1 (1995Q1 to 2002Q4), subsample 2 (2003Q1 to 2010Q4), and subsample 3 (2011Q1 to 2018Q4). Subsample cutoffs are marked by vertical black lines on the connectedness charts displayed in Chapter 3 and Appendices A and B.

The motivation for deconstructing the full period of analysis into subsamples is to explore whether the predictive abilities of each factor is time-varying. The construction of three subsamples containing 8 years each seems fitting given the 24 years of obtained spillover results. From a historical perspective, the structure of these subsamples enables pre-GFC (subsample 1), GFC (subsample 2) and post-GFC (subsample 3) determinant analyses to be conducted.

Each sample period contains quarterly estimates of the 19 spillover measures and quarterly observations of all potential explanatory factors (see Section 4.2). Comprising this collection of measures is 1 aggregated measure (the total spillover index), 12 partial aggregated measures (spillovers 'to all'/'from all' and 'net' spillovers for each of the 4 representative variables) and 6 net pairwise measures ('net pairwise' spillovers between each of the 4 representative variables).

Recall that the spillover measures used in this section were obtained using a rolling window estimation approach. This means that any given estimate was computed using data associated with the preceding 32 quarters. For instance, the first recorded measure for the total spillover index occurs in 1995Q1. This observation was thus computed using data from 1987Q1 to 1994Q4. As such, the primary intent of regression analyses in this section is to explore the power of specific variables in explaining *changes* (i.e. 'dynamics') in the various spillover measures between 1995Q1 and 2018Q4.

4.1.1 Univariate Regression Approach

I begin by employing a simple regression framework where I regress each spillover metric on individual factors. This aims to facilitate a comparison of relative, univariate powers in terms of explaining historical dynamics of macro-financial connectedness. For example, I estimate the following model by regressing the total spillover index ("total") on the variable representative of inflation ("CPI" — see Section 4.2.1):

$$\text{total}_t = \beta_0 + \beta_1 \text{CPI}_t + \varepsilon_t \tag{4.1.1}$$

where total_t is the dependent variable (i.e. total spillover index); CPI_t is the independent variable; β_1 is the slope coefficient; β_0 is the y-intercept; and ε_t is the random error term. In this section, I focus on coefficients of determination (i.e. R-squared values) to facilitate comparative analysis. For the above illustration regression, this coefficient is:

$$R^2 = \frac{\sum(\widehat{\text{total}_t} - \overline{\text{total}})^2}{\sum(\text{total}_t - \overline{\text{total}})^2} \tag{4.1.2}$$

where total_t is the observed value of the total spillover index, $\overline{\text{total}}$ is its mean and $\widehat{\text{total}_t}$ is its fitted value. In this case, R^2 provides an indication of the portion of the total spillover index's variance that the inflation rate explains. That is, how well the example regression model fits the observed data. The straightforward nature of these coefficients allows for simple comparative analysis of the explanatory power of each variable in terms of the assorted spillover metrics.

4.1.2 Grouped Regression Approach

I then examine the relative explanatory power of two different groups of factors: 'macroeconomic' (i.e. "macro") and 'financial'. During these analyses, I regress each spillover metric on only macro factors, only financial factors, and finally, both macro and financial factors. For example, I estimate the following model by regressing the total spillover index on all macro factors introduced in Section 4.2.1 (i.e. "CPI", "GDP" and "UE")

$$\text{total}_t = \beta_0 + \beta_1 \text{CPI}_t + \beta_2 \text{GDP}_t + \beta_3 \text{UE}_t + \varepsilon_t \tag{4.1.3}$$

where total_t is the dependent variable (i.e. total spillover index); CPI_t, GDP_t and UE_t are the independent variables; $\beta_1, \ldots, \beta_3$ are the slope coefficients; β_0 is the y-intercept; and ε_t is the random error term.

In these cases, I focus my comparative analysis on adjusted coefficients of determination (i.e. adjusted R-squared values). The general construction of these adjusted coefficients is:

$$R^2_{adj.} = 1 - (1 - R^2)\frac{n-1}{n-p-1} \tag{4.1.4}$$

where R^2 is the (unadjusted) coefficient of determination, n is the number of quarterly observations and p is the number of independent variables. In this case, $R^2_{adj.}$ provides an indication of how well a given dependent variable's variation is explained by significant independent variables. This metric penalises the addition of irrelevant regressors, and is particularly useful in this case given the uncommon number of variables within the macro and financial subsets (i.e. three and five, respectively).

4.1.3 Multivariate Regression Approach

Finally, I employ a multivariate approach by regressing each spillover metric on all factors at once. For instance, I estimate the following model by regressing the total spillover index on each potential explanatory variable introduced in Section 4.2:

$$\begin{aligned} \text{total}_t = \beta_0 &+ \beta_1\text{CPI}_t + \beta_2\text{GDP}_t + \beta_3\text{UE}_t + \beta_4\text{AUD}_t + \beta_5\text{VOL}_t \\ &+ \beta_6\text{SENT}_t + \beta_7\text{INTER}_t + \beta_8\text{TERM}_t + \varepsilon_t \end{aligned} \tag{4.1.5}$$

where total_t is the dependent variable (i.e. total spillover index); CPI_t, GDP_t, UE_t, AUD_t, VOL_t, SENT_t, INTER_t, and TERM_t are the independent variables; $\beta_1, \ldots, \beta_8$ are the slope coefficients; β_0 is the y-intercept; and ε_t is the random error term.

During this approach I present t-statistics and levels of statistical significance to acutely identify potential determinants of connectedness. Note that in this case, "AUD" (see Section 4.2.2) references the variable representing domestic currency return rather than the Australian Dollar (hereafter, "\$AUD") itself.

The reporting of estimated variable coefficients is foregone when presenting multivariate results. This is due to the idiosyncratic nature of variable construction and differing qualities between spillover metrics (e.g. 'net' spillover metrics are a function of 'from all' and 'to all' metrics). These features make interpreting regression results more challenging, and thus reporting such coefficients is avoided for brevity. Also recall that sensitivity analyses found that while spillover dynamics were generally robust, the magnitudes of spillover estimates differed between econometric specifications. Thus, it seems appropriate to focus on p-values and estimated t-statistics — rather than variable coefficients — to encapsulate statistically significant, directional associations between potential determinants and spillover metrics.

4.2 Description of Data

The choice of which variables to use for explanatory analysis of Australian macro-financial connectedness is open to debate. In this case, choices have been made in accordance with preceding literature on macroeconomic determinants of financial market volatility (see Engle & Rangel, 2008; Paye, 2012), macro-financial determinants of historical bond–equity market correlation (see Asgharian, Christiansen, & Hou, 2016) and predictive associations between financial systemic risk and macroeconomic activity (see L. Allen, Bali, & Tang, 2012).

I group my chosen set of variables into two subsets: macro factors and financial factors. This is done to implement the grouped regression approach specified in Section 4.1. In doing so, I am able to explore notions including whether macro variables are more closely associated with spillovers emerging from the real side (relative to the financial side) of Australia's economy. Additionally, I am able to assess whether financial variables appear more important during periods of financial crises. A summary of data sourcing for this section is provided in Table C.1.1 of Appendix C.

4.2.1 Macroeconomic Factors

In terms of macro factors, I examine the explanatory power of key domestic variables representing the rates of inflation (CPI), economic growth (GDP) and unemployment (UE).

To represent the inflation rate, I utilise the seasonally adjusted, quarterly percentage change in the Consumer Price Index of all items in Australia. This data is obtained from the RBA.

To represent real economic growth, I employ total, seasonally adjusted Australian GDP by expenditure in constant prices. As in Chapter 3, raw quarterly data is obtained from the Federal Reserve Economic Data (FRED) database and transformed into quarter-on-quarter growth rates. Again, this transformation is completed under the presumption that changes in variables on the financial side of the economy are most likely to be related to relative (rather than absolute) movements in real economic variables. Australian GDP is analysed as a potential explanatory variable despite its simultaneous use in the estimation procedures from which the spillover measures are derived. This is based on its wide acceptance as a key indicator of real economic performance (see Engle et al., 2013).

To represent Australian unemployment, I use the seasonally adjusted, harmonised unemployment rate for all persons in Australia. This data is obtained in percentage format at the monthly frequency from FRED. Monthly unemployment data is aggregated to a quarterly frequency by computing quarterly averages.

4.2.2 Financial Factors

In terms of financial factors, I examine the explanatory power of domestic variables representing currency strength (AUD), equity market volatility (VOL), consumer sentiment (SENT) and credit risk (INTER; TERM).

To represent currency strength, I employ Australian Dollar ($AUD) Trade-Weighted Index (TWI) data. The TWI measures the weighted average value of Australia's currency in relation to its major trade partners. Increases reflect a relative currency appreciation while decreases reflect a relative currency depreciation. Data is obtained at a daily frequency from the RBA.

For consistency with data transformations mentioned earlier in this paper, I transform daily $AUD TWI observations into weekly logarithmic returns using the pseudo-weekly approach specified in Section 3.2.2. This accounts for deterministic time variation in the number of days that comprise each month. As before, quarterly logarithmic return volatilities are generated by taking the square root of the sum of squared weekly logarithmic returns for each variable in 12-week blocks.

To represent consumer sentiment, I use Australia's aggregate Consumer Sentiment Index. This data is sourced at a monthly frequency from the Melbourne Institute. Data is then converted to a quarterly frequency by computing quarterly averages.

I analyse the explanatory power of equity market volatility opposed to volatilities in other domestic financial markets. This is based on the comparative responsiveness of stock indices to financial distress (see D'Arcy & Poole, 2010) and intent to keep results concise. To do this, I use daily All Ordinaries Index (ASX: XAO) data and employ the extreme value method for variance estimation introduced in Parkinson's (1980) seminal paper. I attain quarterly return volatilities using a pseudo-calendar approach similar to that used in the transformation of daily $AUD TWI data. First, I compute weekly volatilities based on Parkinson's range-based measure:

$$\sigma_{pw} = \sqrt{\frac{\frac{1}{4 \times ln(2)} \sum_{t=1}^{N} (ln(\frac{H_t}{L_t}))^2}{N}} \tag{4.2.1}$$

where σ_{pw} represents pseudo-weekly volatility, H_t and L_t represent the intraday high and low prices in day t, respectively, and N represents the number of days in the period of calculation (i.e. the number of days in a given pseudo-week). The fine-scale nature of this estimator is advantageous compared to simpler volatility measures that use only one daily observation (e.g. closing prices), thereby ignoring intraday price movements (Brous, Ince, & Popova, 2010). Parkinson's approach to volatility approximation was not used in Chapter 3 due to the unavailability of daily range data for the Australian bond market over the sample period.

Weekly return volatilities are then arranged into pseudo-quarters. The 12 weekly logarithmic return volatilities in each quarter are then averaged to produce a quarterly logarithmic return volatility series for the domestic equity market.

I construct two domestic yield spreads to represent credit risk within the Australian economy. Specifically, I construct two quarterly series which represent an 'interbank spread' (INTER) and a 'term spread' (TERM).

I compute historical interbank spreads (in percentage points) by subtracting the average quarterly yield of the 90-day Australian Dealer Bill from the average quarterly yield of the 90-day Australian Bank-Accepted Bill (BAB). Yields for both bills are computed using raw monthly data from FRED. 90-day Australian BAB data is used due to the unavailability of $AUD LIBOR data over the full sample period. Moreover, the 90-day BAB yield is closely aligned with the 90-day Bank Bill Swap Rate (BBSW); a widely-cited benchmark rate pertinent to the Australian short-term money market. As such, its use seems appropriate in the creation of spreads that resemble the interest rate differential between what investors demand from the Australian government (i.e. short-term government debt) relative to large banks (i.e. short-term interbank loans). In essence, these constructed interbank spreads are intuitively comparable to the U.S. TED spread. Such spreads can be expected to widen during periods of crisis (see K. Schwarz, 2019).

I compute historical 10 year–3 month term spreads by subtracting the yield of the 90-day Australian Dealer Bill from the yield of the 10-year Australian Government Bond. Daily middle rate data for these two instruments are sourced from FRED in percentage point format. For consistency with the frequency of other variables, I compute quarterly averages from these daily observations to produce a quarterly series of term spreads.

4.3 Preliminary Results

4.3.1 Descriptive Statistics of Factors

Table 4.3.1 displays the correlation matrix (a) and basic summary statistics (b) for the previously described explanatory variables. Results in both tables are obtained using a sample period of 1995Q1 to 2018Q4. This time frame aligns with the dynamic estimates of connectedness using the rolling window framework in Chapter 3.

As per Panel A of Table 4.3.1, the pairwise correlations between factors are generally low over the sample period. Exceptions to this claim, however, do exist. Most notable are the correlations between equity market volatility and consumer sentiment (−0.497), and between unemployment and the interbank spread (+0.492). Based on the generally small pairwise correlations, individual factors can be expected to have less power in explaining Australian macro-financial connectedness relative to subsets of factors. This claim is verified in the grouped regression results provided in Section 4.4.2.

As per Panel B of Table 4.3.1, the means and standard deviations of all variables differ across subsamples. Several points should be noted. First, the average rates of inflation and economic growth are lowest in subsample 3, while the average unemployment rate is lowest in subsample 2. Second, average rates of return for the Australian Dollar (AUD) are positive in subsamples 1 and 2, before becoming negative in subsample 3 (likely due to the end of Australia's mining boom — see Tulip, 2014, for instance). As expected, the level of equity market volatility is greatest in subsample 2 — this period contains the GFC. Consumer sentiment is markedly lower in subsample 3 relative to the preceding two subsamples, while it deviates the most in subsample 2. Both the interbank and term spreads also demonstrate higher relative levels of volatility during subsample 2.

Table 4.3.1
Correlation Matrix & Summary Descriptive Statistics — All Factors

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
CPI	1.000							
GDP	-0.211	1.000						
UE	-0.135	0.207	1.000					
AUD	-0.082	0.079	0.000	1.000				
VOL	-0.137	-0.075	-0.135	-0.310	1.000			
SENT	0.123	0.084	0.004	0.288	-0.497	1.000		
INTER	0.224	-0.059	0.098	0.034	-0.125	0.114	1.000	
TERM	-0.134	0.127	0.492	0.000	-0.244	0.120	0.130	1.000

(a) Correlation Matrix — All Factors, Full Sample: 1995–2018

		CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
FULL SAMPLE:	Mean	0.624	0.008	6.022	6.53E-05	0.006	104.606	-4.08E-07	0.005
1995-2018	S.D.	0.515	0.005	1.209	0.004	0.002	7.795	2.27E-05	0.008
SUBSAMPLE 1:	Mean	0.666	0.009	7.415	0.000	0.006	105.206	-1.12E-06	0.008
1995-2002	S.D.	0.720	0.007	0.930	0.004	0.002	5.229	2.29E-05	0.007
SUBSAMPLE 2:	Mean	0.694	0.007	5.065	0.001	0.007	108.259	-1.44E-06	0.002
2003-2010	S.D.	0.419	0.005	0.571	0.005	0.004	10.512	2.35E-05	0.008
SUBSAMPLE 3:	Mean	0.513	0.006	5.584	-0.001	0.006	100.352	1.34E-06	0.005
2011-2018	S.D.	0.318	0.004	0.372	0.003	0.002	3.940	2.24E-05	0.006

(b) Basic Summary Descriptive Statistics — All Factors

Table contains the correlation matrix (a) and basic summary descriptive statistics (b) of the independent variables used in regression-based analyses of Chapter 4. "S.D." represents standard deviation. The set of variables include both real economy (inflation-"CPI", GDP growth-"GDP", and unemployment-"UE") and financial (AUD return-"AUD", equity market volatility-"VOL", consumer sentiment-"SENT", interbank spread-"INTER" and term spread-"TERM") series. Prior to computing summary statistics, all variables excluding the consumer sentiment index ("SENT") were converted from percentage format to decimal format. The summary statistics computed for the consumer sentiment index are obtained from raw figures. All variables are at the quarterly frequency for the full sample period (1995Q1 to 2018Q4), subsample 1 (1995Q1 to 2002Q4), subsample 2 (2003Q1 to 2010Q4) and subsample 3 (2011Q1 to 2018Q4). A full description of data is provided in Section 4.2 with further details in Table C.1.1 of Appendix C. Correlation matrices for the various subsamples are provided in Table C.2.1 of Appendix C. Extended summary descriptive statistics are provided in Table C.2.2 of Appendix C.

For ease of visualisation, the time series plots of explanatory factors are plotted in Figure 4.3.1. Macro factors are plotted in red and financial factors are plotted in purple. The charts reaffirm the above-mentioned discrepancies in each variable's intersample means and standard deviations.

I first inspect the charts of the macro factors. The CPI chart indicates that inflation generally remained in positive territory over the full sample period, with the most notable exceptions in 1997 (AFC) and 2009 (GFC). These exceptions signify instances of deflation. A significant spike in inflation is visible in 2000Q3; this may be attributed to the introduction of the 10% Goods and Services Tax (GST) on the 1st of July 2000. The GDP chart indicates that economic growth was generally positive over the period of analysis. Notable exceptions to this occur in 2000Q4 (−0.387%), 2008Q4 (−0.538%) and 2011Q1 (−0.288%). The lack of two consecutive quarters of negative economic growth is indicative of the fact that Australia's last recession occurred outside the sample period (i.e. 1990–91). The UE chart indicates a gradual decline in unemployment between 1995 and 2008. A well-defined spike in the unemployment rate coincides with the GFC. Between 2011Q2 and 2015Q3, the variable rose from approximately 4.963% to 6.165%, before decreasing for the general remainder of the sample period.

I now consider the charts of the financial factors. The AUD chart represents the return series for the Australian Dollar. Significant variability, as well as volatility clustering, is observable over the sample period. The Australian Dollar (i.e. "$AUD") experiences its greatest relative depreciation around the time of the GFC — this is reflected in a distinct fall in the AUD plot. This is not surprising given the $AUD's known status as a cyclical currency: it tends to appreciate in line with rising global economic activity. The VOL chart also demonstrates a distinct sensitivity of Australian equity market volatility to global economic conditions. Most notable is the fact that volatility grows drastically during periods of offshore macro-financial turbulence. This fact is most noticeable around the periods of the AFC (1997), GFC (2008–09) and Chinese Stock Market Crash (2015). Rising domestic equity market volatility during the GFC is accompanied by a substantial fall in consumer sentiment as per the SENT chart. The Consumer Sentiment Index falls from approximately 116 to 86 between 2007Q2 and 2008Q2. Finally, the INTER and TERM charts display large-scale variability over the full sample period, often fluctuating between positive and negative values. Of perhaps most relevance is the widening of the interbank and term spreads during crises periods. This fact is not surprising given that yields of short-dated instruments (i.e. 3 months) tend to fall relative to those of longer maturities (i.e. 10 years) in anticipation of easing monetary policy during these times.

Figure 4.3.1
Time Series Plots of Macroeconomic and Financial Factors

The macroeconomic (CPI, GDP, UE) and financial (AUD, VOL, SENT, INTER, TERM) factors are plotted for the full sample period (1995Q1 to 2018Q4) in red and purple, respectively. All series are displayed in percentage terms excluding the consumer sentiment index (SENT) which is reported in raw terms. A full description of the formation of each series is provided in Section 4.2 with additional details provided in Table C.1.1 of Appendix C.

4.4 Primary Results

4.4.1 Univariate Regression Approach

I now discuss my findings using the simple, univariate regression approach introduced in Section 4.1. I regress each of the 19 spillover measures on a single one of the aforementioned explanatory variables. I obtain the standard coefficients of determination (i.e. R-squared values) from these regressions and display them in the tables contained in this section. Table 4.4.1 provides results over the full sample period and Tables 4.4.2, 4.4.3 and 4.4.4 provide results using the three subsample periods. Univariate models that display R-squared values in excess of 0.03, 0.04 and 0.07 for the full sample tend to demonstrate variate statistical significance at the 10%, 5% and 1% levels, respectively. In the context of the three subsamples, univariate models that display R-squared values in excess of 0.09, 0.12 and 0.20 tend to demonstrate variate statistical significance at the 10%, 5% and 1% levels, respectively. The comparative statistical significance of explanatory variables is discussed further in Section 4.4.3.

It may be observed that levels of general explanatory power are greatest in subsample 2 relative to the other subsamples. Across the full sample period and all subsamples, unemployment demonstrates the greatest relevance to connectedness dynamics. The term spread also appears to be one of the most relevant explanatory variables of those considered; this is particularly true during subsamples 2 and 3. Other financial variables including equity market volatility, consumer sentiment and the interbank spread demonstrate some explanatory importance. The influence of these variables is largely dependent on the subsample in focus. The relevance of the interbank spread appears to increase over the sample period, displaying growth in its average R-squared value from 0.018 in subsample 1 to 0.064 in subsample 3. $AUD return is generally the least important financial variable, particularly in the latter parts of the sample period. Relative to unemployment, the other macro variables (i.e. inflation and economic growth) demonstrate comparatively limited predictive abilities.

Certain variables show consistent explanatory power for particular spillover metrics. This is the case for unemployment in the explanation of net equity market spillovers, spillovers to all variables from the bond market, and net spillovers for the Equity Market–Housing Market and Housing Market–Real Economy pairs. For these four metrics, unemployment demonstrates the most relative explanatory power across all subsamples. Unemployment also demonstrates consistent explanatory power in the context of net bond market and net housing market spillovers, where it is either the best or second-best determinant in all subsamples.

Consumer sentiment exhibits consistent relative abilities in explaining spillovers from the housing market to all other variables; SENT displays the largest or second largest R-squared value across all subsamples. Lastly, equity market volatility is found to be the most consistent determinant of aggregate spillovers, displaying the second-most explanatory power in all subsamples. While unemployment demonstrates the most power for aggregate spillovers for subsamples 1 and 3, its relative power decreases significantly in subsample 2 where it is ranked sixth of the eight variables for comparative explanatory ability.

Table 4.4.1

Explanatory Power of Individual Factors for Connectedness Measures — Volatilities, Full Sample: 1995–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.018	0.001	0.011	0.031	0.002	0.002	0.015	0.002
Net Spillovers								
Bond	0.037	0.015	0.106	0.004	0.008	0.036	0.006	0.009
Equity	0.003	0.035	0.209	0.002	0.063	0.060	0.013	0.029
Housing	0.015	0.003	0.008	0.000	0.013	0.095	0.009	0.006
Real Economy	0.053	0.005	0.024	0.032	0.070	0.040	0.016	0.059
Spillovers to all others								
Bond	0.012	0.015	0.106	0.009	0.022	0.026	0.008	0.008
Equity	0.000	0.011	0.001	0.047	0.048	0.028	0.003	0.002
Housing	0.028	0.005	0.024	0.003	0.007	0.058	0.003	0.012
Real Economy	0.017	0.003	0.139	0.006	0.006	0.009	0.027	0.000
Spillovers from all others								
Bond	0.035	0.003	0.020	0.000	0.001	0.014	0.000	0.002
Equity	0.002	0.010	0.359	0.045	0.001	0.009	0.005	0.071
Housing	0.012	0.001	0.019	0.005	0.000	0.001	0.054	0.005
Real Economy	0.005	0.000	0.140	0.009	0.036	0.009	0.009	0.100
Pairwise Spillovers								
Bond - Equity	0.002	0.063	0.257	0.002	0.053	0.009	0.010	0.000
Bond - Housing	0.020	0.003	0.000	0.010	0.005	0.118	0.001	0.002
Bond - Real Economy	0.072	0.001	0.019	0.010	0.001	0.029	0.011	0.030
Equity - Housing	0.016	0.001	0.043	0.003	0.002	0.061	0.001	0.153
Equity - Real Economy	0.001	0.000	0.071	0.017	0.073	0.000	0.022	0.040
Housing - Real Economy	0.011	0.007	0.002	0.013	0.080	0.023	0.040	0.127

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table 4.4.2
Explanatory Power of Individual Factors for Connectedness Measures — Volatilities, Subsample 1: 1995–2002

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.027	0.000	0.302	0.006	0.049	0.071	0.001	0.004
Net Spillovers								
Net Bond	0.003	0.014	0.205	0.044	0.005	0.065	0.001	0.064
Net Equity	0.031	0.011	0.114	0.004	0.015	0.002	0.038	0.002
Net Housing	0.001	0.000	0.260	0.010	0.195	0.005	0.000	0.005
Net Real Economy	0.023	0.001	0.001	0.106	0.211	0.095	0.027	0.047
Spillovers to All Others								
Bond to All Other	0.042	0.001	0.193	0.088	0.022	0.101	0.010	0.001
Equity to All Other	0.016	0.017	0.004	0.031	0.002	0.052	0.049	0.001
Housing to All Other	0.009	0.002	0.349	0.010	0.138	0.040	0.002	0.003
Real Economy to All Other	0.037	0.004	0.010	0.108	0.066	0.023	0.070	0.050
Spillovers from All Others								
Bond from All Other	0.013	0.004	0.464	0.004	0.003	0.002	0.009	0.050
Equity from All Other	0.001	0.003	0.202	0.025	0.038	0.060	0.005	0.009
Housing from All Other	0.042	0.008	0.266	0.005	0.033	0.085	0.007	0.000
Real Economy from All Other	0.012	0.006	0.050	0.009	0.046	0.032	0.047	0.005
Pairwise Spillovers								
Bond - Equity	0.068	0.040	0.038	0.007	0.000	0.000	0.018	0.050
Bond - Housing	0.000	0.005	0.062	0.000	0.092	0.019	0.002	0.103
Bond - Real Economy	0.036	0.018	0.188	0.115	0.186	0.208	0.024	0.190
Equity - Housing	0.000	0.001	0.173	0.039	0.150	0.001	0.024	0.030
Equity - Real Economy	0.000	0.001	0.015	0.140	0.103	0.002	0.002	0.001
Housing - Real Economy	0.004	0.009	0.140	0.000	0.031	0.000	0.011	0.006

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for subsample 1 (1995Q1 to 2002Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table 4.4.3

Explanatory Power of Individual Factors for Connectedness Measures — Volatilities, Subsample 2: 2003–2010

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.010	0.091	0.022	0.073	0.209	0.140	0.011	0.022
Net Spillovers								
Net Bond	0.123	0.099	0.196	0.039	0.167	0.152	0.026	0.224
Net Equity	0.022	0.013	0.425	0.001	0.125	0.245	0.009	0.229
Net Housing	0.023	0.122	0.135	0.008	0.083	0.266	0.011	0.072
Net Real Economy	0.119	0.001	0.459	0.022	0.198	0.081	0.046	0.437
Spillovers to All Others								
Bond to All Other	0.107	0.017	0.349	0.052	0.014	0.046	0.002	0.322
Equity to All Other	0.010	0.000	0.464	0.105	0.071	0.109	0.032	0.326
Housing to All Other	0.024	0.160	0.094	0.011	0.284	0.391	0.017	0.135
Real Economy to All Other	0.004	0.016	0.277	0.003	0.156	0.095	0.037	0.120
Spillovers from All Others								
Bond from All Other	0.023	0.165	0.011	0.000	0.009	0.174	0.061	0.000
Equity from All Other	0.012	0.027	0.040	0.093	0.050	0.130	0.113	0.005
Housing from All Other	0.000	0.000	0.021	0.000	0.090	0.005	0.121	0.009
Real Economy from All Other	0.156	0.015	0.060	0.079	0.009	0.000	0.002	0.213
Pairwise Spillovers								
Bond - Equity	0.052	0.000	0.000	0.004	0.021	0.160	0.040	0.081
Bond - Housing	0.036	0.236	0.208	0.075	0.328	0.450	0.006	0.076
Bond - Real Economy	0.113	0.007	0.143	0.009	0.041	0.086	0.002	0.194
Equity - Housing	0.053	0.002	0.556	0.009	0.062	0.093	0.001	0.516
Equity - Real Economy	0.040	0.051	0.008	0.002	0.030	0.001	0.002	0.004
Housing - Real Economy	0.048	0.000	0.566	0.065	0.179	0.050	0.078	0.480

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for subsample 2 (2003Q1 to 2010Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table 4.4.4

Explanatory Power of Individual Factors for Connectedness Measures — Volatilities, Subsample 3: 2011–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.005	0.002	0.147	0.010	0.030	0.124	0.070	0.071
Net Spillovers								
Net Bond	0.049	0.001	0.078	0.019	0.000	0.000	0.000	0.051
Net Equity	0.001	0.001	0.553	0.001	0.000	0.000	0.235	0.173
Net Housing	0.031	0.001	0.110	0.025	0.003	0.012	0.122	0.016
Net Real Economy	0.025	0.001	0.002	0.001	0.004	0.025	0.019	0.000
Spillovers to All Others								
Bond to All Other	0.000	0.001	0.114	0.001	0.000	0.005	0.013	0.002
Equity to All Other	0.003	0.005	0.474	0.003	0.013	0.013	0.190	0.296
Housing to All Other	0.026	0.002	0.000	0.000	0.068	0.007	0.007	0.001
Real Economy to All Other	0.029	0.008	0.000	0.002	0.026	0.188	0.000	0.121
Spillovers from All Others								
Bond from All Other	0.060	0.000	0.001	0.012	0.000	0.005	0.012	0.034
Equity from All Other	0.015	0.007	0.124	0.004	0.035	0.034	0.043	0.228
Housing from All Other	0.000	0.000	0.103	0.026	0.059	0.000	0.070	0.029
Real Economy from All Other	0.076	0.014	0.003	0.005	0.041	0.109	0.013	0.124
Pairwise Spillovers								
Bond - Equity	0.013	0.041	0.162	0.020	0.017	0.015	0.076	0.077
Bond - Housing	0.031	0.001	0.002	0.021	0.001	0.003	0.033	0.011
Bond - Real Economy	0.083	0.051	0.078	0.037	0.048	0.067	0.004	0.000
Equity - Housing	0.034	0.009	0.275	0.010	0.005	0.013	0.127	0.124
Equity - Real Economy	0.001	0.012	0.385	0.002	0.029	0.011	0.144	0.064
Housing - Real Economy	0.018	0.042	0.132	0.014	0.024	0.005	0.032	0.122

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for subsample 3 (2011Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

As per Table 4.4.1, individual variables can be seen to display relatively low levels of explanatory power for the spillover metrics over the full sample period. Tables 4.4.2, 4.4.3 and 4.4.4 elucidate the time-varying nature of explanatory power both in general and for each explanatory variable. To better recognise this notion, I compute the mean of each variable's 19 R-squared values for the full sample and three subsamples. These results are visualised in Figure 4.4.1.

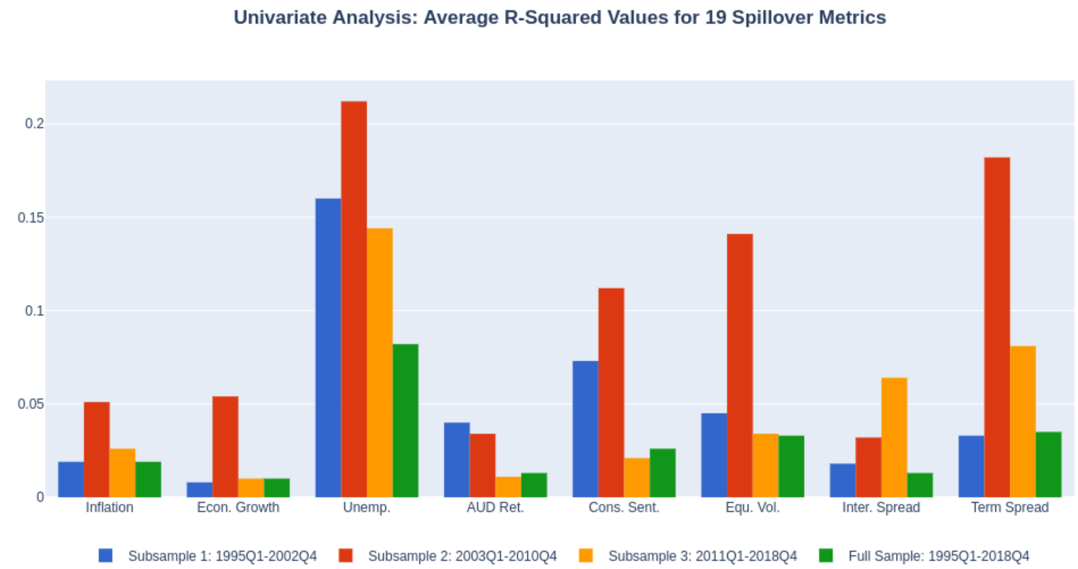

Figure 4.4.1
Univariate Regression Approach: Comparative Analysis of Explanatory Power, Average *R*-squared Values — Volatilities

Figure displays the average R-squared values associated with the 19 univariate regressions conducted for each variable within each sample period. The blue bars provide results for subsample 1 (1995Q1 to 2002Q4). The red bars provide results for subsample 2 (2003Q1 to 2010Q4). The yellow bars provide results for subsample 3 (2011Q1 to 2018Q4). The green bars provide results for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

To further elucidate the relative explanatory power of various factors, I present Figure 4.4.2 which indicates the number of occasions (of a possible 19) that an R-squared value in excess of 0.10 is obtained. A result of 12, for instance, indicates that an R-squared value larger than 0.10 is obtained in 12 of the 19 univariate regressions conducted for a given variable. These 19 regressions are the compilation of regressing each of the 19 spillover metrics on a single given explanatory variable. While the 0.10 threshold is arbitrary, it is consistent with other studies that conduct explanatory analysis for macro-financial connectedness (see Cotter et al., 2017).

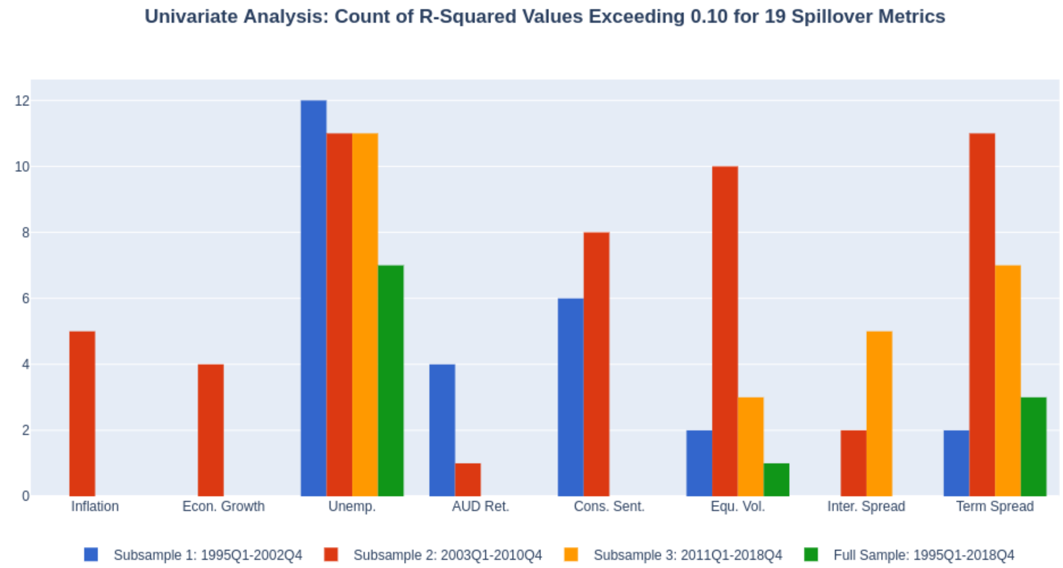

Figure 4.4.2
Univariate Regression Approach: Comparative Analysis of Explanatory Power, Count of *R*-squared Values — Volatilities

Figure displays the number of occasions the R-squared values associated with the 19 univariate regressions conducted for each variable within each sample period exceed 0.10. The blue bars provide results for subsample 1 (1995Q1 to 2002Q4). The red bars provide results for subsample 2 (2003Q1 to 2010Q4). The yellow bars provide results for subsample 3 (2011Q1 to 2018Q4). The green bars provide results for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Only 3 of the 8 variables exhibit R-squared values that exceed 0.10 over the full sample period. This occurs for unemployment on 7 occasions, the term spread on 2 occasions, and equity market volatility on 1 occasion. As per Table 4.4.1, all variables except GDP display at least 1 R-squared value above 0.05 for the set of spillover metrics. This provides initial evidence of economic growth's comparative unimportance in terms of explaining dynamics of connectedness.

The univariate analyses for subsample 1 reinforce unemployment's notable predictive abilities relative to other factors. The R-squared values for unemployment exceed 0.10 on 12 occasions, with those for consumer sentiment and \$AUD return doing so on 2 occasions each. The R-squared values for equity market volatility and the term spread each exceed 0.10 for 1 of the 19 spillover metrics.

In subsample 2, explanatory powers of variables generally rise. Unemployment still displays the greatest power during this period, however, the importance of the other macro variables also grows. The R-squared values for unemployment, inflation and economic growth exceed 0.10 on 11, 5 and 3 occasions, respectively. In terms of financial variables, the term spread and equity market volatility again exhibit the greatest influence, with values exceeding 0.10 on 11 and 10 occasions, respectively. Consumer sentiment does so on 8 occasions, while the \$AUD return and the interbank spread only do so on 1 and 2 occasions, respectively.

In subsample 3, unemployment again displays the greatest relative explanatory power for connectedness. The R-squared values for unemployment exceed 0.10 for 11 of the 19 metrics. The variable with the next most counts of power is the term spread which exceeds this threshold 7 times. Following this is the interbank spread at 5 times. The relevance of equity market volatility falls relative to the two preceding subsamples, with R-squared values exceeding the 0.10 threshold 3 times. Also notable is the fact that R-squared values for several variables do not exceed the threshold at all in subsample 3. This is the case for inflation, economic growth, \$AUD return and consumer sentiment.

Several key points may be established from the above univariate results. First, unemployment displays the greatest predictive abilities for the full sample and all subsample periods. Second, other macro factors become greater determinants of connectedness between 2003Q1 and 2010Q4, despite showing relatively little importance overall. Third, while each financial variable displays some evidence of pronounced power over the analysed period, equity market volatility and the term spread do so most consistently. In general, \$AUD return displays the least explanatory power of the financial variable subset. The interbank spread displays markedly greater predictive abilities between 2011Q1 and 2018Q4 compared to earlier quarters in the sample.

4.4.2 Grouped Regression Approach

I now discuss my findings using the grouped regression approach introduced in Section 4.1. I regress each of the 19 spillover measures on the set of all variables, the set of financial variables, and the set of macro variables. The set of financial factors contains $AUD return, consumer sentiment, equity market volatility, the interbank spread and the term spread. The set of macro factors contains the rates of inflation, economic growth and unemployment.

To account for the fact that each variable set holds a different number of variables, I obtain and report the adjusted coefficients of determination (i.e. adjusted R-squared values) to conduct comparative explanatory analysis. As in the univariate case, I perform regressions for the full sample as well as the three subsample periods. These results are presented in Table 4.4.5.

In this section I use the term "explanatory dominance". This term refers to the case where a given variable subset (e.g. financial) displays a larger adjusted R-squared value relative to the corresponding value for the alternative variable subset (e.g. macro). From Table 4.4.5 it can be seen that the financial subset does not display consistent explanatory dominance over the macro subset for any spillover metric in all subsamples. The converse, however, is not true. The macro subset displays explanatory dominance over the financial subset in all subsamples for 4 of the 19 spillover metrics. This is the case for net bond market spillovers, spillovers from the bond market to all others, and net Equity Market–Housing Market and Housing Market–Real Economy pairwise measures.

The fact that the macro subset exhibits consistent explanatory dominance for spillovers from the bond market is somewhat surprising. This is because conditions on the financial side of the economy may initially be expected to be more relevant in determining spillovers that originate from financial markets relative to conditions on the real side. Clearly, this is not the case — the financial subset does not consistently display explanatory dominance over the macro subset in explaining spillovers stemming from financial markets. A possible cause of this is the aggregation of daily financial data to a common quarterly frequency partly disassociating financial spillover metrics from underlying financial conditions (Cotter et al., 2017).

Table 4.4.5
Explanatory Power of Grouped Factors for Connectedness Measures — Volatilities

	Full Sample: 1995–2018			Subsample 1: 1995–2002			Subsample 2: 2003–2010			Subsample 3: 2011–2018		
	All	Financial	Macro	All	Financial	Macro	All	Financial	Macro	All	Financial	Macro
Aggregate Spillovers												
Total Spillover Index	0.021	0.007	-0.007	0.260	-0.051	0.233	0.369	0.377	0.032	0.183	0.217	0.060
Net Spillovers												
Net Bond	0.315	0.040	0.146	0.203	-0.051	0.194	0.229	0.195	0.269	-0.067	-0.069	0.014
Net Equity	0.266	0.076	0.193	-0.099	-0.125	0.026	0.541	0.429	0.383	0.551	0.219	0.561
Net Housing	0.156	0.164	-0.012	0.388	0.059	0.226	0.255	0.279	0.183	-0.023	-0.004	0.097
Net Real Economy	0.256	0.086	0.065	0.332	0.320	-0.081	0.494	0.443	0.441	-0.187	-0.105	-0.060
Spillovers to All Others												
Bond to All Other	0.296	0.066	0.111	0.267	0.032	0.114	0.232	0.228	0.333	-0.105	-0.167	0.031
Equity to All Other	0.010	0.036	-0.019	0.043	-0.029	-0.062	0.301	0.262	0.413	0.637	0.376	0.437
Housing to All Other	0.102	0.078	0.015	0.411	-0.002	0.292	0.418	0.406	0.180	-0.149	-0.059	-0.074
Real Economy to All Other	0.206	-0.015	0.145	0.308	0.204	-0.033	0.327	0.141	0.228	0.225	0.101	-0.043
Spillovers from All Others												
Bond from All Other	0.037	-0.037	0.038	0.499	-0.106	0.446	0.502	0.324	0.099	0.000	-0.055	-0.022
Equity from All Other	0.386	0.092	0.340	0.275	-0.058	0.144	0.473	0.481	-0.030	0.395	0.282	0.044
Housing from All Other	0.018	0.013	-0.004	0.186	-0.069	0.189	0.099	0.040	-0.084	-0.095	0.017	0.016
Real Economy from All Other	0.173	0.109	0.120	0.053	-0.017	-0.006	0.275	0.185	0.130	0.345	0.077	0.050
Pairwise Spillovers												
Bond - Equity	0.434	0.019	0.278	0.042	-0.105	0.002	0.365	0.325	-0.040	0.022	-0.025	0.151
Bond - Housing	0.100	0.087	-0.010	0.116	0.046	-0.020	0.512	0.410	0.394	-0.175	-0.091	-0.054
Bond - Real Economy	0.181	0.024	0.077	0.646	0.532	0.108	0.219	0.204	0.139	0.029	0.037	0.063
Equity - Housing	0.175	0.180	0.034	0.100	0.070	0.107	0.562	0.494	0.513	0.341	0.156	0.207
Equity - Real Economy	0.118	0.114	0.049	-0.027	0.072	-0.088	-0.125	-0.107	-0.003	0.321	0.128	0.390
Housing - Real Economy	0.199	0.168	-0.006	0.071	-0.109	0.095	0.623	0.508	0.522	0.115	0.027	0.122

Table reports adjusted R-squared values as a representation of the explanatory power of groups of factors: all, financial (i.e. AUD, VOL, SENT, INTER, TERM) and macroeconomic (macro) (CPI, GDP, UE). Explanatory power is estimated by regressing the relevant connectedness measure on a constant and either all factors (financial and macro), only financial or only macro using simple ordinary least squares (OLS). Adjusted R-squared values are obtained from each regression. Regressions are estimated for the full sample period (1995Q1 to 2018Q4), subsample 1 (1995Q1 to 2002Q4), subsample 2 (2003Q1 to 2010Q4) and subsample 3 (2011Q1 to 2018Q4). All variables within the subsets are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Similar to the univariate case, I compute the mean of adjusted R-squared values for each set of variables over the full sample and three subsample periods. These values are attained by taking the average adjusted R-squared values from the 19 regressions conducted for each subset of variables (i.e. 'all', 'financial' and 'macro'). I display my results graphically in Figure 4.4.3.

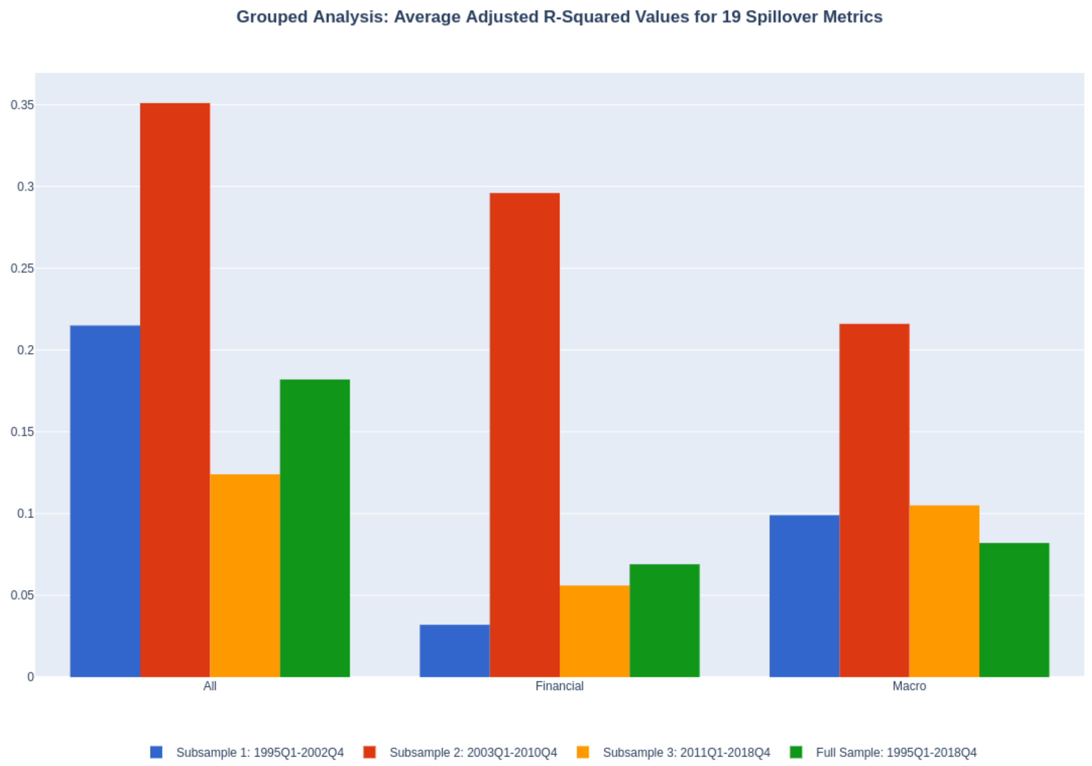

Figure 4.4.3
Grouped Regression Approach: Comparative Analysis of Explanatory Power, Average Adjusted R-squared Values — Volatilities

Figure displays the average adjusted R-squared values associated with the 19 grouped regressions conducted for each variable subset within each sample period. The blue bars provide results for subsample 1 (1995Q1 to 2002Q4). The red bars provide results for subsample 2 (2003Q1 to 2010Q4). The yellow bars provide results for subsample 3 (2011Q1 to 2018Q4). The green bars provide results for the full sample period (1995Q1 to 2018Q4). "All" represents the set of all eight previously specified variables. "Financial" represents the set of five previously specified financial variables (i.e. AUD, SENT, VOL, INTER, TERM). "Macro" represents the set of three previously specified macroeconomic variables (i.e. CPI, GDP, UE). All variables within the subsets are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Clearly, each subset of variables displays time-varying levels of explanatory power. As expected, the complete set of variables exhibits comparatively greater power than the financial and macro subsets for all periods of analysis. In subsample 1, the macro subset displays a larger average adjusted R-squared value (0.099) than that of the financial subset (0.032). This suggests that between 1995Q1 and 2002Q4, macro variables generally held more power relative to the financial variables when explaining connectedness dynamics. In subsample 2, this theme is reversed. Between 2003Q1 and 2010Q4, average adjusted R-squared values are larger for the financial subset (0.296) relative to the macro subset (0.216). The results of subsample 3 are akin to those of subsample 1 in suggesting that the macro subset is a greater determinant of dynamics compared to the financial subset. This is substantiated by the average adjusted R-squared value for the macro subset (0.105) exceeding that of the financial subset (0.056).

These results reaffirm the time-varying nature of determinants of Australian macro-financial connectedness. The comparatively larger assembly of adjusted R-squared values in subsample 2 relative to those in subsamples 1 and 3 is consistent with univariate regression findings. Namely, the entire set of variables appears to better explain connectedness dynamics between 2003Q1 and 2010Q4 relative to other portions of the full sample period. A possible interpretation of this result is that spillover metrics are linked closer to macro-financial fundamentals during periods leading up to and during macro-financial distress.

I now examine the grouped regression results further by tallying the number of occasions (of 19) that the financial subset boasts greater explanatory power over the macro subset (and vice versa). That is, I record the number of times each subset displays explanatory dominance for each period of analysis. My results are visualised in Figure 4.4.4.

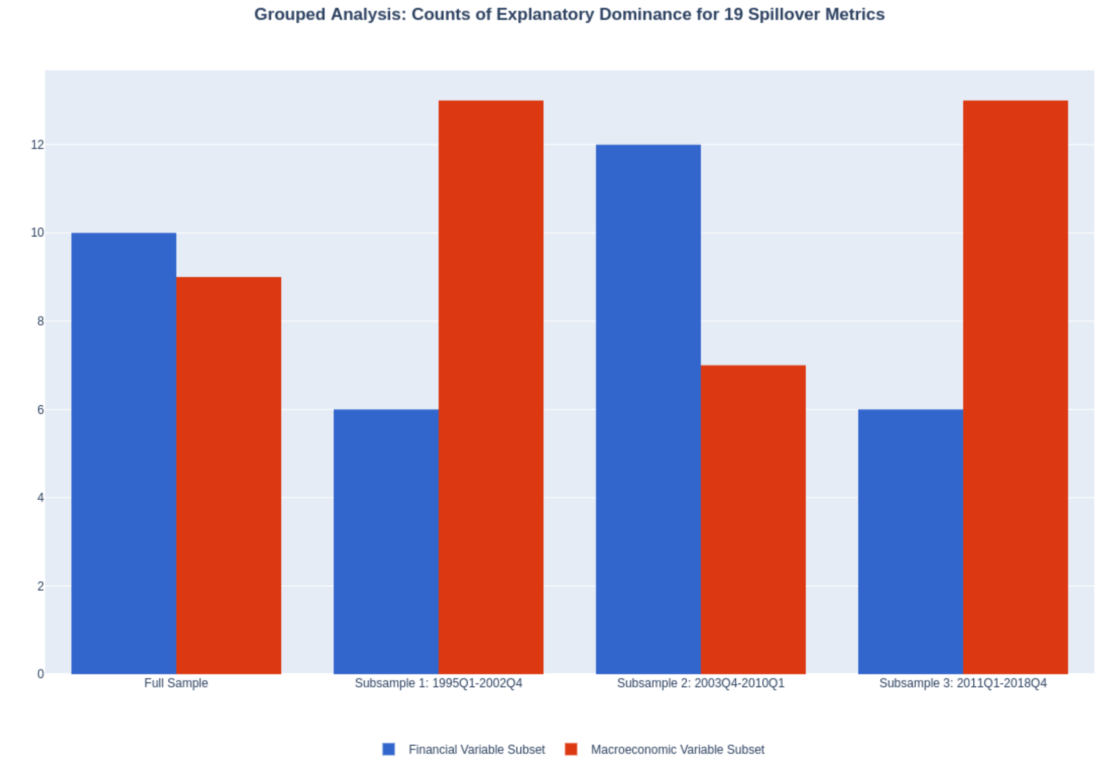

Figure 4.4.4
Grouped Regression Approach: Comparative Analysis of Explanatory Power, Counts of Explanatory Dominance — Volatilities

Figure displays the number of occasions the adjusted R-squared values associated with the 19 grouped regressions conducted for a given subset ("financial" or "macro") exceeds the corresponding adjusted R-squared values for the alternate subset. That is, for example, when the adjusted R-squared value associated with regressing the 'total spillover index' on the financial subset is larger than the adjusted R-squared value associated with regressing the 'total spillover index' on the macro subset. The case where a given subset's adjusted R-squared value exceeds the corresponding value for the alternate subset is termed "explanatory dominance". The blue bars provide counts of explanatory dominance for the subset of financial variables (AUD, SENT, VOL, INTER, TERM). The red bars provide counts of explanatory dominance for the subset of macroeconomic variables (CPI, GDP, UE). All variables within the subsets are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

I begin by inspecting the full sample results. Of the 19 metrics, the adjusted R-squared values for the financial subset exceed those from the corresponding macro subset in the majority of instances (10 to 9). Moreover, there exists a greater amount of negative values for the macro variable set relative to the financial subset (6 to 2); this is indicative of poor model selection. A potential interpretation here is that the combined set of financial factors holds slightly greater relative explanatory power than the combined set of macro factors between 1995Q1 and 2018Q4. The fact that no subset distinctly dominates the other over the full sample period signifies that conditions on both the financial and real sides of the economy influence connectedness dynamics.

I now move onto the grouped regression results for each subsample period. In subsample 1, the adjusted R-squared values for the macro subset exceed those from the corresponding financial subset for 13 of 19 spillover metrics. This prevailing explanatory dominance of the macro variables is a stark contrast to the results for the full sample period both in terms of nature and magnitude (i.e. the financial set's explanatory dominance in 10 of 19 instances). Such results suggest that the combined set of macro factors holds greater explanatory power than the combined set of financial factors between 1995Q1 and 2002Q4.

In subsample 2, the adjusted R-squared values for the financial subset exceed those from the corresponding macro subset from 12 of the 19 spillover metrics. Thus, a transition from macro explanatory dominance to financial explanatory dominance between subsamples 1 and 2 is evident. This provides further evidence of the time-varying nature of factors governing macro-financial connectedness.

The results in subsample 3 indicate a transition back towards macro explanatory dominance in general. This is evidenced by the fact that the adjusted R-squared values for the macro subset exceed those from the corresponding financial subset in 13 of 19 cases.

In summary, financial factors appear to hold more explanatory power relative to the examined macro factors over the full sample period. Interestingly, however, in the quarters neighbouring subsample 2 (which contains the GFC), macro factors assert comparative explanatory dominance. These findings provide support for the time-varying nature of determinants of Australian macro-financial connectedness.

4.4.3 Multivariate Regression Approach

I now discuss my findings using the multivariate regression approach introduced in Section 4.1. I regress each of the 19 spillover measures on the full set of explanatory variables. I report t-statistics and p-values to encapsulate statistically significant, directional associations between variables and spillover metrics. Results are displayed in Table 4.4.6 for the full sample period (1995Q1–2018Q4), Table 4.4.7 for subsample 1 (1995Q1–2002Q4), Table 4.4.8 for subsample 2 (2003Q1–2010Q4) and Table 4.4.9 for subsample 3 (2011Q1–2018Q4). Several distinct relationships are identifiable between the regressors and spillover metrics. I focus on relationships emerging when all instances of statistical significance for a given variable coefficient display a consistent t-statistic sign (i.e. positive or negative).

Beginning with the most aggregated measure, there appears to exist a negative relationship between equity market volatility and the total spillover index. This is evidenced by t-statistics of -2.034 (at the 10% level of significance; hereafter, "X% sig.") and -2.654 (5% sig.) for VOL's corresponding coefficients in subsamples 1 and 3, respectively. A consistently positive relationship between \$AUD return and total spillovers is also observable. This is evidenced by t-statistics of 2.152 (5% sig.) for the full sample and 2.879 (1% sig.) for subsample 2.

I now identify consistent and significant directional relationships between regressors and the partial aggregated measures. Net bond market spillovers appear negatively related to the inflation rate. This is evidenced by t-statistics of -3.227 (1% sig.) and -1.106 (10% sig.) for the full sample and subsample 1, respectively. Net equity market spillovers display a negative relationship with the term spread; t-statistics of -2.001 (5% sig.) for the full sample and -1.961 (10% sig.) for subsample 2 are recorded. Net housing market spillovers appear positively related with both consumer sentiment and equity market volatility. I record t-statistics for consumer sentiment of 2.855 (1% sig.) and 2.622 (5% sig.) for the full sample and subsample 1, respectively. I record t-statistics for equity market volatility of 4.605 (1% sig.) for the full sample and 1.925 (10% sig.) for subsample 2. Lastly, there appears to be a negative relationship between net real economy spillovers and consumer sentiment, but a positive relationship between these spillovers and the inflation rate. The former statement is validated by t-statistics of -1.893 (10% sig.), -2.853 (1% sig.) and -2.104 (5% sig.) for consumer sentiment for the full sample, subsample 1 and subsample 2, respectively. The positive relationship between net real economy spillovers and the inflation rate is supported by t-statistics of 3.325 (1% sig.) for the full sample and 1.823 (10% sig.) for subsample 1.

Spillovers from the bond market to all others appear negatively related to equity market volatility. I record t-statistics of -3.137 (1% sig.) and -1.728 (10% sig.) for the full sample and subsample 1, respectively. Spillovers from the equity market to all others also appear negatively related to equity market volatility. This notion is supported by t-statistics of -1.992 (10% sig.) in subsample 1 and -2.459 (5% sig.) in subsample 3. Spillovers from the housing market to all others display a positive relationship with consumer sentiment: t-statistics of 2.002 (5% sig.) and 1.784 (10% sig.) are observed for the full sample and subsample 1, respectively. Spillovers from the real economy to all other variables do not appear to hold any consistent directional relationships with any particular regressor. An illustration of this is unemployment's t-statistic of 2.260 (5% sig.) in subsample 1 and −3.107 (1% sig.) in subsample 2. Despite the statistical significance of unemployment's coefficients in these cases, t-statistic signs are uncommon and so no time-consistent directional associations are discernible.

Spillovers from all others to the bond market appear positively related to the inflation rate. This is evidenced by t-statistics of 2.475 (5% sig.) for the full sample and 1.879 (10% sig.) for subsample 3. Spillovers from all others to the equity market appear negatively associated with the unemployment rate; t-statistics of −6.723 (1% sig.) and −3.831 (1% sig.) are recorded for the full sample and subsample 1, respectively. Spillovers from all others to the equity market also appear positive related to $AUD return; t-statistics of 2.884 (1% sig.) for the full sample and 3.905 (1% sig.) for subsample 2 are recorded. Spillovers from all other variables to the housing market do not explicitly display any consistent directional relationships with the examined explanatory variables. Lastly, spillovers from all other variables to the real economy display a consistent, positive relation to the term spread. This is indicated by t-statistics of 1.687 (10% sig.), 2.291 (5% sig.) and 2.718 (5% sig.) for the full sample, subsample 2 and subsample 3, respectively.

In terms of net pairwise measures, the Bond Market–Housing Market pair appears positively associated with the term spread. This is indicated by t-statistics of 3.926 (1% sig.), 2.099 (5% sig.) and 2.326 (5% sig.) for the full sample, subsample 1 and subsample 2, respectively. A negative relationship between the unemployment rate and Equity Market–Real Economy pair is also observed. This is signified by t-statistics of −1.791 (10% sig.) and −3.197 (1% sig.) for the full sample and subsample 3, respectively. No clear directional relationships exist in the context of the Bond Market–Housing Market and Equity Market–Housing Market pairwise metrics.

Three consistent directional relationships exist for the Bond Market–Real Economy pair. First, a negative relationship between this metric and equity market volatility is noticeable: t-statistics of −2.270 (5% sig.), −3.169 (1% sig.) and −2.094% (5% sig.) are recorded for the full sample, subsample 1 and subsample 2, respectively. Negative relationships between the Bond Market–Real Economy net measure and the interbank and term spreads also exist. This is evidenced by t-statistics of 1.678 (10% sig.) and 2.963 (1% sig.) for the interbank spread, and t-statistics of 2.115 (5% sig.) and 2.021 (10% sig.) for the term spread, for the full sample and subsample 1, respectively.

Finally, two positive variable associations exist for the Housing Market–Real Economy pairwise measure. This is the case for consumer sentiment and the interbank spread. I record t-statistics of 2.460 (5% sig.) and 2.713 (5% sig.) for consumer sentiment for subsamples 1 and 2, respectively. These two subsamples also display respective t-statistics of 1.739 (10% sig.) and 1.787 (10% sig.) for the interbank spread.

Table 4.4.6

Multivariate Analyses of Connectedness Measures — Volatilities, Full Sample: 1995–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	1.856*	-0.061	-0.647	2.152**	0.301	1.258	-1.549	0.676
Net Spillovers								
Net Bond	-3.227***	-1.158	-5.325***	0.064	-2.736***	-3.519***	1.602	2.481**
Net Equity	0.016	0.677	4.874***	-0.594	2.228**	-1.177	-2.001**	-1.146
Net Housing	1.387	-0.143	-0.158	0.990	2.855***	4.605***	0.888	0.274
Net Real Economy	3.325***	1.322	3.467***	-0.791	-1.893*	0.749	-1.593	-3.123***
Spillovers to all others								
Bond to All Other	-2.019**	-0.909	-5.236***	0.848	-3.476***	-3.137***	1.568	2.716***
Equity to All Other	-0.099	0.742	-0.117	1.327	1.266	-0.561	-0.630	-0.647
Housing to All Other	2.061**	-0.145	-0.708	1.345	2.002**	3.501***	-0.845	0.397
Real Economy to All Other	2.570**	0.193	4.745***	-0.058	-0.045	1.186	-2.454**	-1.215
Spillovers from all others								
Bond from All Other	2.475**	0.685	1.997**	0.837	0.165	1.673*	-0.608	-0.628
Equity from All Other	-0.176	0.259	-6.723***	2.884***	-0.998	0.697	1.694*	0.520
Housing from All Other	1.498	-0.046	-0.925	0.869	-0.485	-0.349	-2.488**	0.281
Real Economy from All Other	0.064	-1.182	3.078***	0.792	2.031**	0.900	-1.814*	1.687*
Pairwise Spillovers								
Bond - Equity	-1.555	-1.886*	-7.665***	0.152	-3.242***	-0.678	2.058**	3.926***
Bond - Housing	-1.957*	0.054	-0.720	-0.251	-1.006	-3.848***	-0.054	-0.376
Bond - Real Economy	-3.407***	-0.722	-3.066***	0.377	-1.451	-2.270**	1.678*	2.115**
Equity - Housing	-1.297	-1.124	0.093	-1.011	-1.722*	-2.790***	-0.052	2.946***
Equity - Real Economy	-0.530	0.273	-1.791*	0.564	2.885***	0.702	-1.292	-0.977
Housing - Real Economy	-1.609	-1.560	-1.331	0.509	2.460**	0.533	1.739*	3.511***

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Regressions are estimated for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table 4.4.7

Multivariate Analyses of Connectedness Measures — Volatilities, Subsample 1: 1995–2002

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	-0.878	0.658	-3.695***	-0.115	0.681	-2.034*	1.158	0.035
Net Spillovers								
Net Bond	1.585	-1.218	2.918***	1.543	-0.003	0.043	-0.969	1.212
Net Equity	-0.777	0.460	1.209	-0.204	-0.098	-0.666	0.901	-0.837
Net Housing	-1.881*	0.443	-4.088***	-0.312	2.622**	-1.029	2.117**	0.776
Net Real Economy	1.823*	-0.101	0.895	-0.612	-2.853***	1.932*	-2.722**	-0.826
Spillovers to all others								
Bond to All Other	-0.022	0.486	-3.161***	1.643	-0.020	-1.728*	1.569	0.566
Equity to All Other	-1.722*	0.955	-1.518	0.037	0.294	-1.992*	2.224**	-0.099
Housing to All Other	-1.408	0.302	-4.603***	-0.086	1.784*	-1.712	1.672	0.928
Real Economy to All Other	2.009*	-0.334	2.260**	-1.176	-1.433	1.275	-3.277***	-1.526
Spillovers from all others								
Bond from All Other	-1.552	1.625	-5.736***	0.026	-0.015	-1.637	2.384**	-0.648
Equity from All Other	-1.469	0.776	-3.831***	0.327	0.559	-2.012*	2.035*	0.977
Housing from All Other	-0.340	0.033	-3.216***	0.180	0.188	-1.697	0.523	0.697
Real Economy from All Other	0.742	-0.364	2.211**	-0.976	1.321	-0.453	-1.509	-1.229
Pairwise Spillovers								
Bond - Equity	1.712	-1.254	-0.567	0.737	-0.779	1.100	-1.237	2.099**
Bond - Housing	0.937	-0.406	2.229**	0.313	-1.407	0.859	-1.534	-1.837*
Bond - Real Economy	-1.591	0.575	2.049*	0.972	3.695***	-3.169***	2.963***	2.021*
Equity - Housing	0.336	-0.468	1.911*	-0.576	-1.790*	-0.216	-0.143	0.649
Equity - Real Economy	0.155	-0.068	-0.577	1.687	1.329	0.324	0.754	0.142
Housing - Real Economy	-1.914*	-0.216	-2.615**	-0.805	1.089	-1.034	1.787*	-0.234

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Regressions are estimated for the sample period of 1995Q1 to 2002Q4 (subsample 1). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table 4.4.8
Multivariate Analyses of Connectedness Measures — Volatilities, Subsample 2: 2003–2010

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	-0.509	-1.361	0.570	2.879***	-1.952*	1.015	0.168	0.223
Net Spillovers								
Net Bond	-1.109	1.276	0.351	-0.155	1.028	-0.093	-0.001	1.030
Net Equity	0.537	0.591	3.045***	-2.574**	0.201	-1.732*	-1.961*	0.156
Net Housing	0.011	-1.261	-0.873	1.273	0.350	1.925*	1.352	-0.327
Net Real Economy	0.986	-0.409	-2.031*	0.730	-2.104**	-1.114	-0.173	-1.058
Spillovers to all others								
Bond to All Other	-0.633	0.763	1.420	0.104	-0.473	-0.062	-0.182	0.950
Equity to All Other	0.442	0.067	2.033*	0.293	-0.071	-0.125	0.134	0.596
Housing to All Other	0.202	-1.378	0.801	1.329	-0.847	2.097**	0.625	-1.819*
Real Economy to All Other	-0.659	-1.351	-3.107***	2.443**	-1.401	-0.603	-0.344	0.824
Spillovers from all others								
Bond from All Other	1.429	-1.572	2.069**	0.599	-3.516***	0.101	-0.376	-0.581
Equity from All Other	-0.170	-0.724	-1.572	3.905***	-0.366	2.215**	2.859***	0.549
Housing from All Other	0.215	0.237	2.157**	-0.311	-1.462	-0.37	-1.223	-1.598
Real Economy from All Other	-1.995*	-1.258	-1.620	2.285**	0.654	0.525	-0.240	2.291**
Pairwise Spillovers								
Bond - Equity	-0.688	0.964	-1.408	1.664	0.891	3.033***	1.349	2.326**
Bond - Housing	-0.518	2.277**	1.673	-0.582	1.502	-1.232	-1.063	-0.570
Bond - Real Economy	-1.608	-1.365	-0.032	-1.639	-0.658	-2.094**	0.110	1.142
Equity - Housing	0.607	0.829	2.612**	-1.726*	0.106	-0.244	-1.059	1.936*
Equity - Real Economy	-0.874	0.944	-0.251	-0.064	1.363	0.728	-0.411	-0.239
Housing - Real Economy	0.173	0.887	3.295***	0.025	2.713**	2.599**	0.473	1.016

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. Regressions are estimated for the sample period of 2003Q1 to 2010Q4 (subsample 2). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table 4.4.9
Multivariate Analyses of Connectedness Measures — Volatilities, Subsample 3: 2011–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.279	1.183	-0.309	-0.560	0.786	-2.654**	-0.688	-2.069**
Net Spillovers								
Net Bond	-1.106*	-0.581	0.600	1.172	0.201	0.467	-0.035	1.129
Net Equity	-0.376	-0.180	-4.303***	-0.953	-1.148	-0.387	-1.109	-0.440
Net Housing	0.940	0.178	1.535	-0.518	0.699	0.523	0.536	-0.466
Net Real Economy	0.828	0.895	0.536	-0.378	-0.363	-1.241	0.253	-0.846
Spillovers to all others								
Bond to All Other	0.700	0.540	2.096**	0.311	0.490	-0.672	-0.355	-0.976
Equity to All Other	1.082	1.361	-3.160***	-1.138	-1.762*	-2.459**	-1.381	-2.843***
Housing to All Other	0.750	0.272	0.886	-0.089	1.575	0.595	-0.198	-0.772
Real Economy to All Other	-2.655**	-0.489	-1.439	-0.090	0.179	-1.986*	0.994	1.794*
Spillovers from all others								
Bond from All Other	1.879*	1.162	1.484	-0.926	0.282	-1.173	-0.322	-2.181**
Equity from All Other	1.855*	2.042*	-0.023	-0.605	-1.264	-2.976***	-0.780	-3.449***
Housing from All Other	-0.060	0.140	-0.493	0.411	1.142	0.174	-0.764	-0.438
Real Economy from All Other	-3.641***	-1.337	-2.052*	0.241	0.522	-1.054	0.858	2.718**
Pairwise Spillovers								
Bond - Equity	0.349	-0.539	1.735*	-0.612	0.835	-0.244	0.188	0.065
Bond - Housing	-1.003	-0.586	-0.606	0.788	-0.112	0.255	-0.354	1.138
Bond - Real Economy	-0.851	0.541	0.825	1.817*	-0.230	0.861	0.504	0.109
Equity - Housing	1.729*	-0.161	-1.650	-1.677	-1.383	-0.982	-1.725*	-1.140
Equity - Real Economy	-1.085	-0.931	-3.197***	-1.335	0.209	-0.362	-0.435	0.078
Housing - Real Economy	0.755	-1.347	1.458	-0.177	0.748	1.603	-0.647	1.355

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Regressions are estimated for the sample period of 2011Q1 to 2018Q4 (subsample 3). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

It is evident that particular variables are generally more statistically significant than others. For ease of interpretation, I provide counts of statistical significance (at the 1% and 5% levels) for each variable over the full sample period in Figure 4.4.5. While statistical significance at the 1%, 5% and 10% levels are reported in the tables, I use the term "significant" to describe variables whose coefficients have a p-value less than 0.05 in the discussion that follows. This enables the comparison of predictive abilities at a finer scale.

Of the 19 spillover metrics, unemployment is statistically significant in 10 instances (i.e. 10 regressions), whereas economic growth is not significant in any. Other variables also display notable consistency in terms of statistical significance when explaining connectedness dynamics. Consumer sentiment is significant in 9 instances, while equity market volatility, the term spread and inflation are each significant in 7 instances.

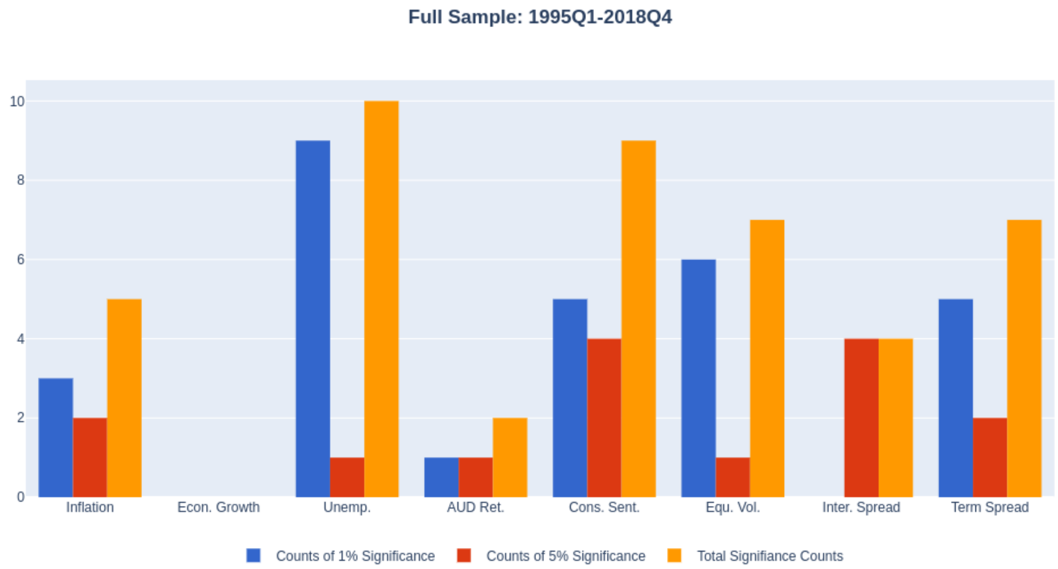

Figure 4.4.5
Multivariate Regression Approach: Comparative Analysis of Explanatory Power, Counts of Statistical Significance for Full Sample — Volatilities

Figure displays the number of occasions a variable is statistically significant in the 19 multivariate regressions conducted within the full sample period (1995Q1 to 2018Q4). The blue bars provide counts of statistical significance at the 1% level. The red bars provide counts of statistical significance at the 5% level (excluding counts of statistical significance at the 1% level). The yellow bars provide the sum of counts of statistical significance represented by the blue and red bars. "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

To determine whether particular variables are more important during certain time periods compared to others, I proceed to examine the time-segmented regression results. For ease of interpretation, I again provide counts of statistical significance (at the 1% and 5% levels) for each variable within each subsample. These results are presented in Figure 4.4.6.

In subsample 1, unemployment is the most statistically significant variable in a general sense; it is significant in 12 of 19 cases. Of second most importance is the interbank spread which is significant in 6 instances. During subsample 2, unemployment demonstrates yet again the most significance (6 instances), however, additional variables also rise to importance. Namely, AUD return and equity market volatility are both statistically significant for 5 spillover metrics, while consumer sentiment is significant for 3. In subsample 3, unemployment perpetuates its comparative significance, again exhibiting the most counts. This result, however, is weaker than those of other subsamples: significance is recorded in only 4 of 19 instances. Other variables also show a comparable relevance in this subsample, with equity market volatility and the term spread each displaying 3 significance counts.

Interestingly, the total number of statistically significant variables differs between subsamples. Subsamples 1 and 2, for instance, both exhibit 23 statistically significant terms in the 19 conducted regressions (i.e. of a total 152: $19 \times 8 = 152$). Contrastingly, subsample 3 only contains 15 statistically significant terms. These results suggest that the dynamics of Australian macro-financial connectedness are better explained between 1995Q1 and 2010Q4 compared to the latter third of the sample period (i.e. 2011Q1 to 2018Q4). This notion is bolstered by findings from the grouped regression analyses. Namely, the entire set of factors was found to hold greater explanatory ability in subsample 2 relative to subsample 3.

One perhaps surprising result from the multivariate approach was that economic growth consistently failed to show statistical association with spillover dynamics. This was the case for not only the full sample period, but also for subsamples 1 and 3. Exploring the reasons for this are outside the scope of this study, however, may be of interest to future researchers.

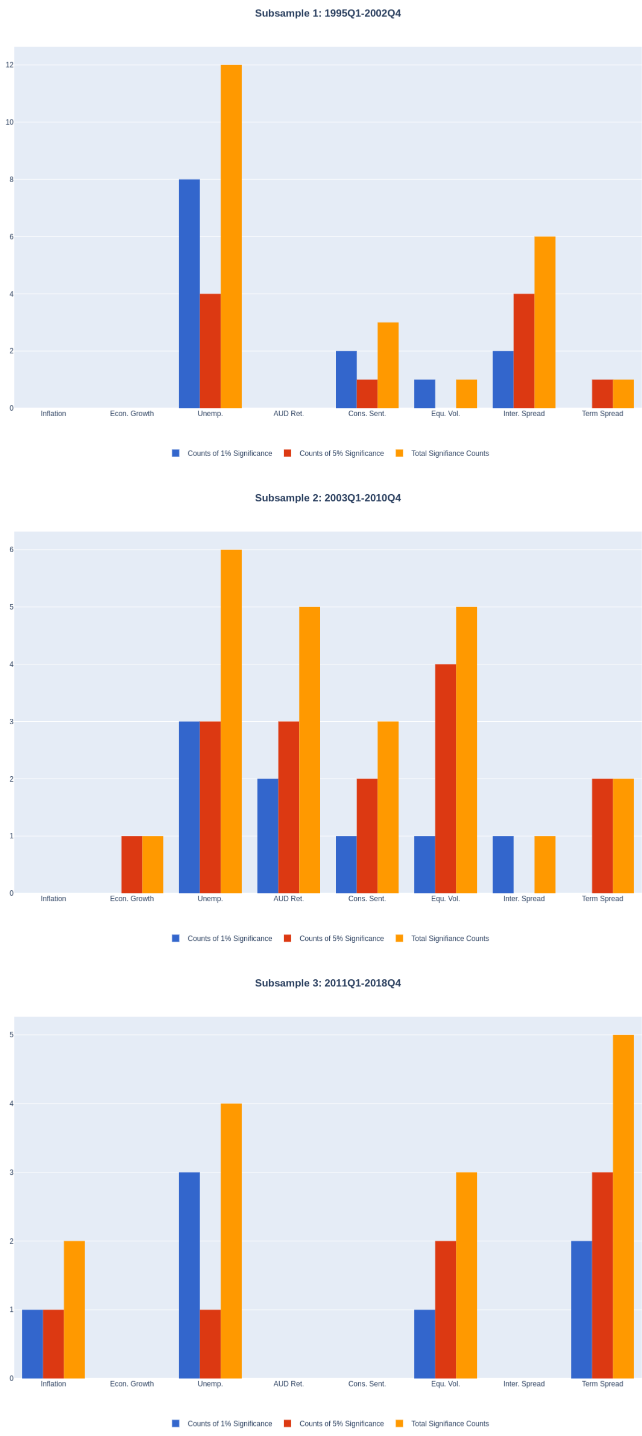

Figure 4.4.6
Multivariate Regression Approach: Comparative Analysis of Explanatory Power, Counts of Statistical Significance for Subsamples — Volatilities

Figure displays the number of occasions a variable is statistically significant in the 19 multivariate regressions conducted within each subsample. Subsample 1 spans from 1995Q1 to 2002Q4; subsample 2 spans from 2003Q1 to 2010Q4; subsample 3 spans from 2011Q1 to 2018Q4. The blue bars provide counts of statistical significance at the 1% level. The red bars provide counts of statistical significance at the 5% level (excluding counts of statistical significance at the 1% level). The yellow bars provide the sum of counts of statistical significance represented by the blue and red bars. "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth volatilities. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

4.5 Key Findings: Determinants of Australian Macro-Financial Connectedness

In the preceding sections of this chapter I employed time-segmented regression techniques to facilitate explanatory analysis of Australian macro-financial connectedness. To crystallise these results, I present the following 12 key findings.

1. General levels of explanatory power for the chosen set of variables is greatest in subsample 2 and smallest in subsample 3.
2. Of the macroeconomic variables and all variables in general, the rate of unemployment displays the most explanatory power for dynamics of macro-financial connectedness.
3. The rates of inflation and economic growth display relatively little explanatory power over the period of analysis, however, are most prominent in subsample 2.
4. Of the financial variables, equity market volatility and the term spread display the most explanatory power in general.
5. The explanatory power associated with equity market volatility is comparatively high over the full period of analysis, peaking in subsample 2.
6. The explanatory power associated with the term spread increases in consecutive subsamples. The explanatory power associated with the interbank spread increases markedly in subsample 3.
7. Of the financial variables, $AUD return displays the least explanatory power over the full sample period.
8. Macroeconomic factors are more relevant than financial factors in explaining net bond market spillovers, spillovers from the bond market to all others, Equity Market–Housing Market net pairwise spillovers and Housing Market–Real Economy net pairwise spillovers.
9. Over the full sample period, the subset of financial factors holds greater explanatory power than the subset of macroeconomic factors in general.
10. The subset of macroeconomic factors asserts explanatory dominance over the subset of financial factors in subsample 2.
11. Consistent and statistically significant, positive associations exist between:
    (a) The total spillover index and $AUD return;
    (b) Net housing market spillovers and consumer sentiment;
    (c) Net housing market spillovers and equity market volatility;
    (d) Net spillovers for the real economy and the inflation rate;
    (e) Spillovers from the housing market to all others and consumer sentiment;
    (f) Spillovers from all others to the bond market and the inflation rate;

(g) Spillovers from all others to the equity market and $AUD return;

(h) Spillovers from all others to the real economy and the term spread;

(i) Bond Market–Housing Market net pairwise spillovers and the term spread;

(j) Housing Market–Real Economy net pairwise spillovers and consumer sentiment;

(k) Housing Market–Real Economy net pairwise spillovers and the interbank spread.

12. Consistent and statistically significant, negative associations exist between:

    (a) The total spillover index and equity market volatility;

    (b) Net bond market spillovers and the inflation rate;

    (c) Net equity market spillovers and the term spread;

    (d) Net spillovers for the real economy and consumer sentiment;

    (e) Spillovers from the bond market to all others and equity market volatility;

    (f) Spillovers from all others to the equity market and the unemployment rate;

    (g) Bond Market–Real Economy net pairwise spillovers and equity market volatility;

    (h) Bond Market–Real Economy net pairwise spillovers and the interbank spread;

    (i) Bond Market–Real Economy net pairwise spillovers and the term spread;

    (j) Equity Market–Real Economy net pairwise spillovers and the unemployment rate.

Comparison to U.S. Findings

Interestingly, many of the major findings in this chapter share similarities with Cotter et al.'s (2017) study of U.S. macro-financial connectedness. First, the authors find that unemployment demonstrates particularly prominent predictive abilities in the context of time-varying U.S. macro-financial connectedness. Second, the VIX index and their constructed term spread also display notable explanatory power in multiple instances. Third, levels of explanatory power are greatest around the time of the GFC.

Of perhaps greater interest, however, are the dissimilarities in the results of the aforementioned study and those of this paper. In acknowledging these, future studies are able to examine the structural differences between U.S. and Australian macro-financial connectedness. First, this study documents greater levels of relative explanatory importance for currency valuation (i.e. "AUD") and sentiment (i.e. "SENT") compared to the corresponding factors employed in Cotter et al.'s study. Second, the authors find markedly greater predictive abilities for macroeconomic factors compared to financial factors over their full sample period. This is at odds with the results associated with the Australian macro-financial system; the financial subset is found to have slightly greater explanatory power in general. Lastly, Cotter et al. (2017) uncover a statistically significant, positive association between aggregate levels of U.S. connectedness and the VIX index. The opposite is found in this study; the total spillover index appears negatively associated with domestic equity market volatility.

Supplementary Results: Return & Growth Rates

Primary analysis in this section focused on explaining variations in spillover metrics derived from return and growth *volatilities*. Results associated with explaining variations in spillover metrics derived from raw return and growth *rates* were reserved for Appendix C. While not discussed at length, these results are broadly consistent with those presented in this chapter.

Of note is the fact that unemployment generally displays the most power of the entire set of variables in explaining dynamics of connectedness. Equity market volatility and the term spread also appear consistently important, to a much greater extent than other financial variables including $AUD return. Similarly, the other macroeconomic variables (i.e. the rate of inflation and economic growth) appear comparatively less important relative to unemployment.

Results obtained using rates data also indicate that the full set of explanatory factors displays the most explanatory power in subsample 2 and least in subsample 3. Financial factors are found to have the most predictive abilities in general, as well as in subsamples 1 and 3. The macro variable subset demonstrates explanatory dominance over the financial subset in subsample 2. These results are all consistent with those obtained from spillover metrics computed using volatility data.

Consistent and statistically significant directional associations also exist between certain factors and both sets of spillover metrics. Namely, the term spread is positively associated with spillovers to the real economy from all other variables computed using both rates and volatility data. Unemployment is negatively associated with spillovers to the equity market from all other variables for both sets of results.

Chapter 5
Discussion & Conclusion

5.1 Applications of Study

Capturing historical dynamics and determinants of macro-financial connectedness is a pursuit pertinent to many stakeholders. The spillovers discussed in this study's primary analysis elucidate understandings of the origination and diffusion of volatilities within the Australian macro-financial system. From a macro perspective, comprehending the interdependencies between the financial and real economic sectors is of pivotal interest when designing economic policy and monitoring systemic risk. From a micro perspective, an awareness of historical spillover episodes may more effectively guide asset pricing and portfolio management strategies. In this section, I briefly establish some applicatory scope for the results of this study.

First and foremost, this study confirms the existence of volatility spillovers within the Australian macro-financial system. As discussed in Chapter 3, spillovers were especially present between domestic financial markets. On this note, it may be possible for market participants to use historical dynamics to forecast future dynamics. Volatility spillover forecasting is of significant interest to portfolio managers as said spillovers influence underlying portfolio risk exposures. By using historical dynamics to forecast those in the future and accompanying risk exposures, managers should theoretically be able to engage in more prudent investment behaviour. The variables found to be most associated with connectedness (see Chapter 4) may provide a basis for volatility spillover forecasting.

Notably, macro-financial spillovers were also found to become more prominent during and leading up to periods of turbulence. From the perspective of investors, this is concerning as it implies that the process of financial hedging is of greatest difficulty during times where it is arguably most important. Elevated volatility spillovers in times of crises also imply that diversification benefits may be smaller than expected. That is, cross-asset diversification may reap less than expected hedging benefits due to unanticipated interdependencies in risk exposure.

Some studies have proposed methods of integrating information regarding volatility spillovers into efficient portfolio construction. These studies often rely on notions of portfolio diversification as developed by Markowitz (1952). The motivation for considering volatility spillovers in this context stems from their capacity to influence portfolio return attributes. An example of this is Heymans and Brewer (2015) who introduce a measure of market beta that incorporates volatility spillover dynamics. They indicate that a relatively efficient portfolio is one that not only hedges against non-systematic risk (i.e. displays unit correlation with the market), but also contains assets with minimal volatility spillover effects.

Leveraging knowledge regarding volatility spillovers may also enable enhanced pricing of financial instruments. This is especially the case for instruments with cross-asset exposure such as diversified exchange-traded funds (ETFs). As volatility represents risk, volatility spillovers can be interpreted to represent transfers of risk between segments of the macro-financial system. Arguably, akin to volatility's presence in numerous theoretical asset-pricing models (see, for instance, Danielsson, 1994; Holmstrm & Tirole, 2001; O'Hara, 2003), the inclusion of volatility spillovers in the pricing of assets with cross-market exposure may be warranted. This notion is relevant to both theoreticians in the field of asset pricing (i.e. academics) and issuers of financial instruments (i.e. industry).

From a policy standpoint, this study's results enable regulators to better understand the structure of the domestic macro-financial system. Acknowledging market co-movements is integral when designing policies that avoid adverse consequences. Such consequences include the destabilising outcomes of financial market contagion. Of particular interest to policy-makers are the net pairwise metrics presented in Chapter 3. These allow historical spillover structures between individual segments of the Australian economy to be examined. Macro-prudential regulators, for instance, are able to take cognisance of the fact that the bond market became a more prominent net transmitter of volatility shocks to the equity market over the sample period.

The clear presence of interdependencies between Australian macro-financial segments means that regulators should thoroughly consider the ancillary impacts of policies intended to directly affect any one segment. This is particularly the case for monetary policy as periods of more active RBA behaviour have historically coincided with periods of elevated spillovers. In terms of policies aimed at managing systemic risk, this study's findings are somewhat reassuring. Despite showing noticeable short-run fluctuations, aggregate connectedness in the Australian macro-financial system did not display long-run trends. If aggregate connectedness was instead found to have increased over the sample period, the effectiveness of such policies may have been questioned.

5.2 Limitations & Future Research

This thesis endeavoured to document and inspect the dynamics and determinants of Australian macro-financial connectedness from 1995Q1 to 2018Q4. While such feats have arguably been accomplished with rigour and robustness, several limitations of this study should be acknowledged. By identifying these limitations, future researchers may be able to pursue their alleviation.

The most outstanding limitation of this study involves data aggregation. Aggregation was performed to avoid obstacles arising from the use of mixed-frequency data. On the dynamics side, the use of mixed-frequency data in the context of the Diebold-Yilmaz framework causes obstacles involving the non-standard structure of forecast error variance decomposition arrays. On the determinants side, the use of mixed-frequency data during explanatory analysis generally necessitates the incorporation of more sophisticated, non-linear least squares techniques. Despite all available observations being used in the transformation of daily (e.g. bond and equity) and monthly (e.g. unemployment) data into common, quarterly series, information losses associated with aggregation are inevitable. That is, intra-quarterly information contained in the series of relatively higher frequency (see Tables A.2.1 and C.1.1) are not used at optimal capacity. The loss of such information may cloud the reporting of true spillover dynamics.

While theoretically possible to leverage data of varying frequencies in this study of connectedness, such activities are onerous to execute. Due to time and resource constraints, these undertakings lay outside the scope of this project. Future research may look to alleviate aggregation issues via the use of mixed-frequency techniques. One may look to Cotter et al. (2017) to compute Diebold-Yilmaz spillover indices using mixed-frequency vector autoregression models. Of note is the fact that this study found the use of high-frequency data allowed spillover indices to respond quicker to known developments in the macro-financial system. This is arguably advantageous in terms of capturing the most accurate dynamics of system connectedness. In saying this, however, their comparison of results obtained from common- and mixed-frequency approaches indicated that both methods captured broadly similar connectedness dynamics.

Findings from other studies including Andersen, Bollerslev, Diebold, and Labys (2003) and Green (2004) also support the use of high-frequency financial data in macro-financial analysis. This support stems from findings of significant intraday effects of macroeconomic announcements on short-term financial market activity. Accordingly, recent spillover approaches that integrate intraday financial data may also be of interest to future researchers (see, for instance, Nishimura & Sun, 2018).

Another data concern is inherited from the use of the Established House Price Index. This metric, which served to represent Australia's housing market during spillover estimation, is spliced to match the period of analysis. Methodological changes to this index's estimation meant data had to be extrapolated between 1987Q1 and 2001Q4 using records from earlier, antiquated releases. It is also worth mentioning that data availability necessitated this study's use of data from the 1st of January 1987 to 31st of December 2018. While issues of time-constrained data access are difficult to relieve, they remain limitations of this study nonetheless.

From a procedural standpoint, recall that the documentation of spillover dynamics in Chapter 3 focused primarily on volatilities in rates of return and growth. Several points may be made about this focus. First, these volatilities were generally computed by taking squared logarithmic rates of change. Although consistent with other studies and easy to implement, future researchers may wish to explore alternative methods of volatility approximation. This, for example, includes measures of realised volatility. Moreover, the variable representing equity market volatility in Chapter 4 was generated using a range-based approach introduced by Parkinson (1980). This approach enabled the efficient incorporation of intraday variation in equity data. While advantageous, it was not implemented during preceding analysis of dynamics for computational consistency with bond market volatility. In this case, the use of Parkinson's approximation method was precluded by the unavailability of intraday range data for the bond market. This reality may be viewed as methodologically limitative.

As a research extension, future studies may use an enlarged representation of the domestic macro-financial system. Of particular recommendation is the inclusion of additional segments of the financial sector. This includes, for instance, data representative of the Australian credit market. The incorporation of such elements arguably enables a more comprehensive analysis of macro-financial connectedness to be conducted. Such inclusions can be expected to amplify system-wide estimates of spillovers based on the nature of their composition (see Chapter 4). International variables may also be included in the construction of the Australian macro-financial system. Based on Australia's nature as a small, open economy, the roles of international variables in domestic spillover transmission are likely to be of critical interest. By including variables representative of the U.S. bond and equity market, for instance, additional questions may be answered. Of particular note is whether international financial markets are more influential than Australian financial markets in the context of domestic shock transmission.

In addition to expanding the scope of spillover analysis, additional regressors may be considered when examining the potential determinants of connectedness. Which additional variables to include is subjective, however, similar to above, consideration for international factors is likely to be worthwhile. This is especially the case given this project's explicit focus on primarily domestic explanatory variables. In this study, the most internationally exposed regressor was that of $AUD return. The variable's creation relied on Trade-Weighted Index data that was naturally contingent on domestic currency strength in the context of foreign exchange market activity. Future research may wish to examine the powers of other internationally-exposed variables involving trade data and foreign macroeconomic indices (e.g. U.S. industrial production). In terms of domestic regressors, explanatory variables involving levels of firm, government and household debt may also be considered. The latter may be of most interest given the amplification of Australian household debt over the past three decades (Loukoianova, Wong, & Hussiada, 2019). Moreover, in line with its research scope, this paper explored *potential* determinants of connectedness dynamics. Future research may wish to focus specifically on causal identification to better understand and pinpoint the drivers of connectedness dynamics. Detecting causation may be accomplished by assessing whether determinants provide any *marginal* predictive content in the context of spillover forecasting models (for more information, refer to Chang, McAleer, & Tansuchat, 2010; Morley, 2016).

It may also be of interest to examine whether recent developments such as the rise of e-trading and trends in asset management have influenced macro-financial spillover dynamics. Miyajima and Shim (2014) find that herd behaviour in investors flows have reinforced directional asset price fluctuations within emerging markets. By examining whether similar behaviour has magnified spillovers in the Australian macro-financial system, a better understanding of domestic spillover channels may be gained. This is particularly the case in terms of determining the importance of recurring financial market phenomena in driving spillover dynamics. Comprehending such channels is vital for policy-makers in terms of designing stability frameworks and theoreticians in developing models that properly characterise macro-financial linkages.

Building on this paper's findings, several adjunct research avenues may be explored. Of key interest are the specific causes behind the domestic bond market's growing shock transmission role in the post-GFC era. Results presented in Chapter 4 may be able to guide such analysis; the predictive abilities of the term spread were found to grow over this time frame. The fact that the bond market's rise to prevalence coincides with unprecedentedly low cash rate targets may also provide a starting point for causal identification.

The use of mixed data sampling (MIDAS) techniques introduced by Ghysels, Santa-Clara, and Valkanov (2004); Ghysels, Sinko, and Valkanov (2007) and Ghysels (2016) may also be considered in future explanatory analysis. These techniques make optimal use of high-frequency data and may enable an enriched understanding of spillover determinants. Alternative time-segmented regression approaches are also possible. Of particular note is the use of rolling regression techniques to acutely analyse time-varying changes in the significance and explanatory power of regressors. Such analysis may permit changes in predictive abilities to be better attributed to known macro-financial events and conditions. Tests for structural breaks within these regressions may also complement such inquiry.

Finally, this thesis provided preliminary evidence of feedback loops between the financial and real sectors of the Australian economy. Such loops materialised in the form of mounting shock transmission between these sectors in pre-crisis periods. Similar phenomena had been discussed in preceding theoretical work including Bernanke et al. (1996). The presence and origination of adverse macro-financial feedback loops in Australia may thus be a fruitful area of research. The countering of self-reinforcing spillover dynamics and effectiveness of current stabilisation policy are further prospective topics of interest. The policy implications of the short-run variations in macro-financial connectedness chronicled in this paper may also be examined.

5.3 Concluding Remarks

This thesis explored the dynamics and determinants of Australian macro-financial connectedness between 1995Q1 and 2018Q4. I focused on connectedness stemming from return and growth volatilities due to its substantial practical interest for a variety of stakeholders. Findings obtained using raw rates of return and growth were reserved for Appendix B.

To document historical dynamics, I employed domestic bond, equity and housing market data to represent the financial side of the economy. To represent the real side, I leveraged gross domestic product data. Dynamics of connectedness were uncovered by implementing Diebold and Yilmaz's (2012) generalised spillover framework. Of key note was the finding that short- and medium-run fluctuations in connectedness were more prominent than long-run trends. Such fluctuations coincided with known macro-financial events and conditions, with general connectedness levels rising in periods of mounting turbulence. The role of the bond market in terms of shock transmission was found to substantially grow over the period of analysis.

To uncover historical determinants, I examined the predictive abilities of an assortment of macroeconomic (i.e. "macro") and financial variables. This variable set was constructed based on findings from related literature. In terms of macro variables, I focused on rates of inflation, economic growth and unemployment. In terms of financial variables, I considered Australian Dollar returns, consumer sentiment, equity market volatility, an interbank spread and a term spread. Of these variables, unemployment demonstrated the most consistent power in explaining connectedness dynamics. Consumer sentiment, equity market volatility and the term spread also displayed comparatively large power, with the relevance of the term spread growing over the sample period. The assemblage of variables exhibited the greatest explanatory power between 2003Q1 and 2010Q4, with the financial subset displaying particular relevance during this time.

For those in the finance industry, the documentation of spillover dynamics and potential determinants may be useful in the development of tactful portfolio management strategies. For regulators, these results help foster a more complete understanding of macro-financial interdependencies, thus better informing the consequences of economic policy.

Future research may wish to explore the theoretical underpinnings of this study's data-driven results. The application of mixed-frequency econometric techniques may also be considered as a methodological extension. It may be particularly interesting to further investigate the bond market's heightening role as a shock transmitter. Additionally, causal identification of the drivers behind dynamics of Australian macro-financial connectedness remains an important area of research.

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Appendices

Appendix A

Dynamics of Connectedness: Volatilities

A.1 Recount of Macro-Financial History

Table A.1.1
Summary of Global & Australian Macro-Financial Events — Full Sample Period: January 1987 to December 2018

Quarter	Month	Key Event
1987Q2	April	Formation of ASX
1987Q4	October	Black Monday Crash
1989Q1	January	George H.W. Bush elected US president
1989Q4	November	Fall of Berlin Wall
1990Q3	July	Beginning of US 1990's Recession (to 1991Q1)
1990Q3	August	Iraq's Invasion of Kuwait & Beginning of Gulf War (to 1991Q1)
1991Q1	February	Peak of Indian Economic Crisis
1991Q3	July	Beginning of Commonwealth Bank privatisation
1991Q3	September	Beginning of Finnish Banking Crisis
1991Q4	December	Paul Keating elected Aus. prime minister
1991Q4	December	Collapse of Soviet Union
1992Q3	July	Introduction of compulsory superannuation in Australia
1992Q3	September	Peak of Swedish Banking Crisis
1993Q1	January	Bill Clinton elected US president
1993Q1	March	Beginning of Qantas privatisation
1993Q4	November	Creation of European Union
1994Q1	January	Signature of NAFTA between US-Mexico-Canada
1994Q2	May	Nelson Mandela elected South African president
1994Q4	December	Mexican Peso Crisis
1995Q4	November	Dow Jones reaches 5,000 close level for first time
1996Q1	March	John Howard elected Aus. prime minister
1996Q2	April	Port Arthur Massacre
1997Q3	July	Beginning of Asian Financial Crisis
1997Q3	July	Handover of Hong Kong

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Table A.1.1 – continued from previous page

Quarter	Month	Key Event
1997Q4	November	Beginning of Telstra privatisation
1998Q3	August	Beginning of Ecuador Financial Crisis
1998Q3	August	Beginning of Russian Financial Crisis
1998Q3	August	Collapse of Long Term Capital Management
1998Q4	October	ASX demutualises and becomes listed
1999Q1	January	Introduction of the Euro
1999Q1	January	Brazilian Currency Crisis
1999Q4	November	Aus. republic referendum defeated
2000Q1	March	Beginning of Dot Com Bubble Crash
2000Q3	July	Introduction of Aus. Goods and Services Tax (GST)
2000Q4	September	Beginning of Sydney Olympic Games
2000Q4	December	Beginning of Turkish Banking Crisis
2001Q1	January	George W. Bush elected US president
2001Q1	March	AUD drops below 50US cents for first time
2001Q1	March	Collapse of HIH Insurance
2001Q1	March	Beginning of US 2001 Recession (to 2001Q4)
2001Q2	May	Collapse of One-Tel
2001Q3	August	Peak of Turkish Economic Crisis
2001Q3	September	September 11 Attacks
2001Q3	September	Collapse of Ansett Airlines
2001Q3	October	Collapse of Enron
2001Q4	December	Argentina Currency Crisis & Protests
2002Q3	July	Beginning of Uruguay Banking Crisis
2002Q3	July	Nasdaq Composite Index hits lowest level since 1997
2002Q4	October	Bali Bombings
2002Q4	November	Outbreak of SARS virus in China
2002Q4	December	Beginning of Venezuelan Oil Strikes
2003Q1	March	Invasion of Iraq
2004Q4	December	Boxing Day Tsunami
2005Q1	March	Junk status of General Motors and Ford debt

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Table A.1.1 – continued from previous page

Quarter	Month	Key Event
2005Q3	August	Hurricane Katrina
2005Q4	December	Cronulla Riots
2006Q1	January	Australia-East Timor Agreement
2006Q1	March	ASX & SFE Merger Announcement
2006Q2	May	Beginning of US FOMC hiking path
2007Q3	August	Beginning of Global Financial Crisis (GFC)
2007Q3	August	Beginning of US FOMC cutting path
2007Q4	December	Kevin Rudd elected Aus. prime minister
2008Q1	February	Enactment of US Economic Stimulus Act of 2008
2008Q1	March	Bear Sterns' Takeover
2008Q3	July	Enactment of US Housing and Economic Recovery Act of 2008
2008Q3	July	Oil prices reach record high of US$145
2008Q3	September	Fannie Mae & Freddie Mac Takeover
2008Q3	September	Collapse of Lehman Brothers
2008Q4	December	US federal funds rate hits 0%
2009Q1	January	Barack Obama elected US president
2009Q1	February	Announcement of $42bn Aus. National Building Economic Stimulus Plan
2009Q1	March	Dow Jones hits market low
2009Q2	May	Release of Supervisory Capital Assessment Program (SCAP) results
2009Q4	November	Beginning of Venezuelan Banking Crisis
2010Q2	April	Beginning of European Sovereign Debt Crisis
2010Q2	May	May 2010 Flash Crash
2010Q2	June	Julia Gillard elected Aus. prime minister
2010Q4	December	Beginning of Arab Spring Protests
2011Q1	January	Coal prices reach all-time high
2011Q1	January	Queensland Floods
2011Q1	February	Iron ore prices reach all-time highs
2011Q1	March	Japanese Tsunami & Nuclear Disaster
2011Q4	October	Threat of US government shutdown
2011Q4	October	Greek Economy Referendum

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Table A.1.1 – continued from previous page

Quarter	Month	Key Event
2012Q3	July	Enactment of Aus. Carbon Tax
2012Q3	September	Peak of Australian Mining Boom
2013Q2	June	Kevin Rudd elected Aus. prime minister
2013Q3	August	RBA cash rate target hits historic low of 2.5%
2013Q3	September	Tony Abbott elected Aus. prime minister
2013Q3	September	US government shutdown
2013Q4	November	Beginning of Ukrainian Crisis
2014Q2	June	ECB introduction of negative interest rates
2014Q3	July	Beginning of Brazilian Economic Crisis
2014Q3	July	Abolition of Aus. Carbon Tax
2014Q4	December	Sydney Lindt Café Siege
2014Q4	December	Beginning of Russian Financial Crisis
2014Q4	December	China becomes world's largest economy
2015Q2	June	Chinese Stock Market Bubble Burst
2015Q2	June	Signing of Australia-China Free Trade Agreement
2015Q3	September	Malcolm Turnbull elected Aus. prime minister
2016Q1	January	BOJ introduction of negative interest rates
2016Q2	June	Brexit Referendum
2016Q3	August	RBA cash rate targets hits historic low of 1.5%
2016Q4	November	Donald Trump elected US president
2018Q1	January	Beginning of US-China Trade War intensification
2018Q3	August	Beginning of Turkish Currency and Debt Crisis

Table provides a summary of key global and domestic (Australian) financial, geopolitical and macroeconomic events over the sample period: 1st of January 1987 to 31st of December 2018.

A.2 Data Sourcing

Table A.2.1
Summary of Data Sourcing — Analysis of Historical Dynamics

Variable	Description	Original Frequency	Sample Frequency	Source	Identification Code/s
Real Economy ("GDP")	GDP by Expenditure, Constant Prices, Seasonally Adjusted	Quarterly	Quarterly	Federal Reserve Economic Data (FRED)	NAEXKP01AUQ661S
Financial Sector - Bond Market ("BON")	Australia 10-year Government Bond Yield	Daily	Quarterly	Datastream	S06122
Financial Sector - Equity Market ("EQU")	All Ordinaries Index (ASX: XAO)	Daily	Quarterly	Yahoo! Finance	AORD
Financial Sector - Housing Market ("HOU")	Established House Price Index, Weighted Average of 8 Capital Cities	Quarterly	Quarterly	Australian Bureau of Statistics (ABS)	A2333613R, A83728456R

Table describes the sourcing of the representative variables used in spillover estimation in Chapter 3. A full description of data is provided in Section 3.2.

A.3 Robustness: Order of VAR Model — Volatilities

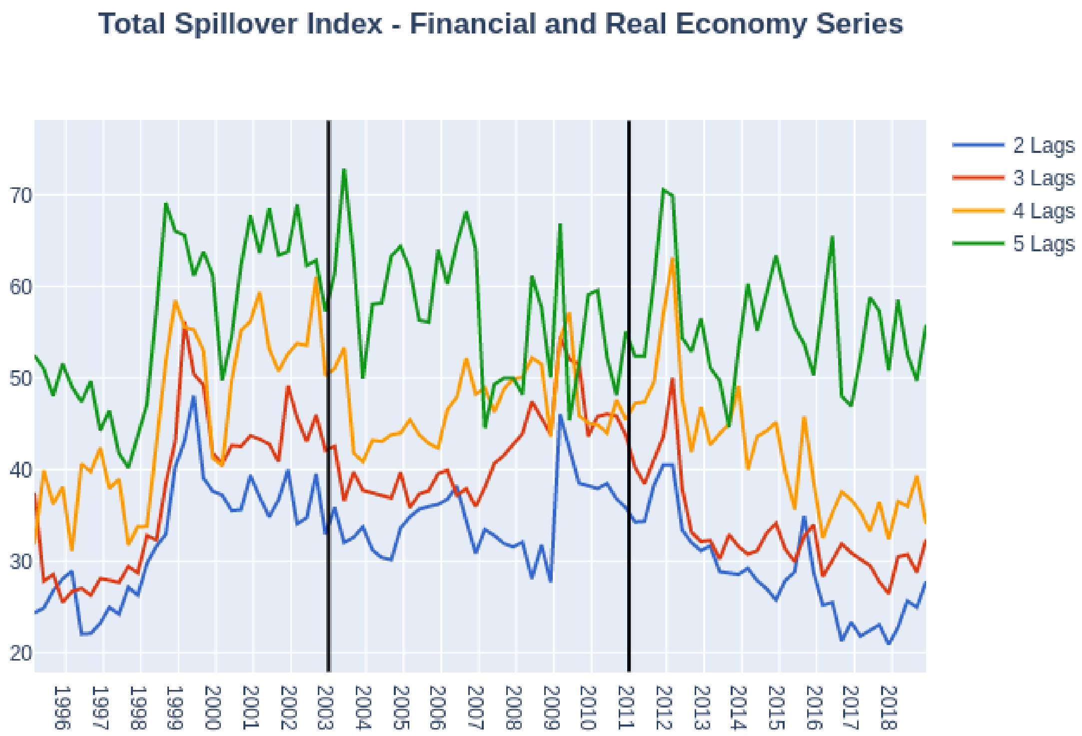

Figure A.3.1
Sensitivity of VAR Order: Total Spillover Index — Volatilities

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of various orders (2, 3, 4 and 5).

Figure A.3.2
Sensitivity of VAR Order: Partial Connectedness Measures — Volatilities

Figure plots the spillovers transmitted by each variable to all others (first column), received by each variable from all others (second column) and the net spillovers for each variable to/from all others (third column) for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of various orders (2, 3, 4 and 5).

Figure A.3.3
Sensitivity of VAR Order: Net Pairwise Spillovers — Volatilities

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The charts only display net pairwise spillovers in one direction for any given variable pair. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of various orders (2, 3 4 and 5).

A.4 Robustness: Forecast Horizon — Volatilities

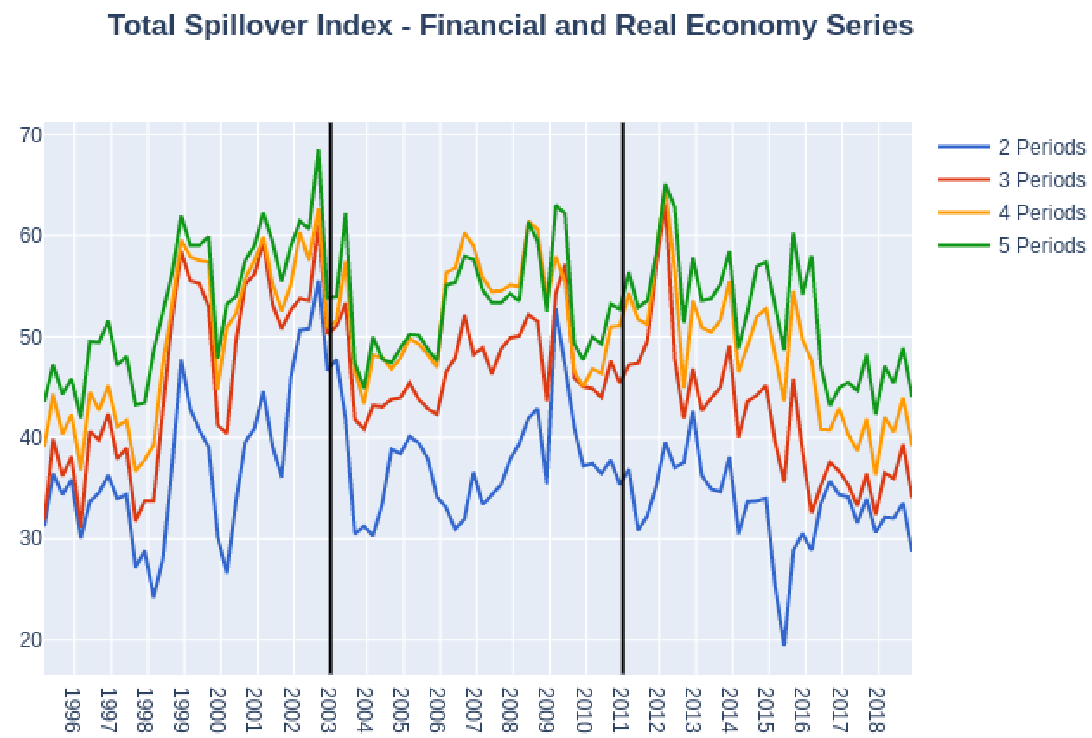

Figure A.4.1
Sensitivity of Forecast Horizon: Total Spillover Index - Volatilities

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 32-quarter rolling window, VAR models of order 4 and forecast horizon of various sizes (2 to 5 quarters).

Figure A.4.2
Sensitivity of Forecast Horizon: Partial Connectedness Measures — Volatilities

Figure plots the spillovers transmitted by each variable to all others (first column), received by each variable from all others (second column) and the net spillovers for each variable to/from all others (third column) for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic volatilities are used for the real economy series GDP. Values are calculated using a 32-quarter rolling window, VAR models of order 4 and forecast horizon of various sizes (2 to 5 quarters).

Figure A.4.3
Sensitivity of Forecast Horizon: Net Pairwise Spillovers — Volatilities

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The charts only display net pairwise spillovers in one direction for any given variable pair. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 32-quarter rolling window, VAR models of order 4 and forecast horizon of various sizes (2 to 5 quarters).

A.5 Robustness: Rolling Window — Volatilities

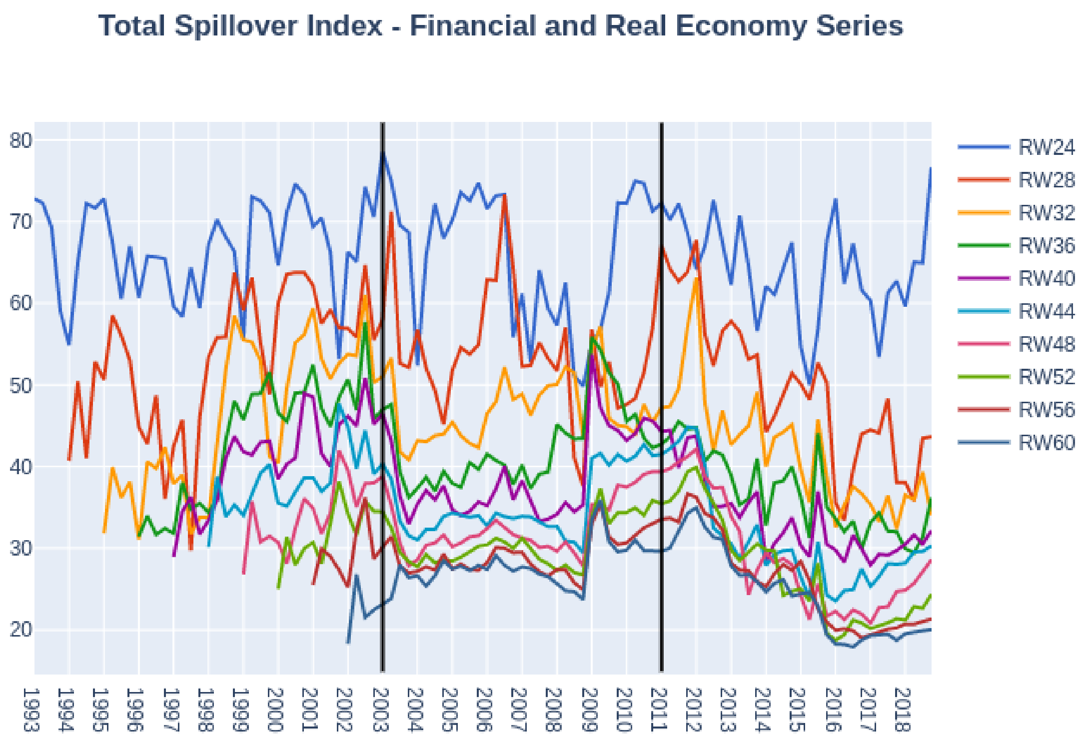

Figure A.5.1
Sensitivity of Rolling Window: Total Spillover Index — Volatilities

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, VAR models of order 4 and various sized rolling windows (24 to 60-quarters).

Figure A.5.2
Sensitivity of Rolling Window: Partial Connectedness Measures — Volatilities

Figure plots the spillovers transmitted by each variable to all others (first column), received by each variable from all others (second column) and the net spillovers for each variable to/from all others (third column) for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, VAR models of order 4 and various sized rolling windows (24 to 60-quarters).

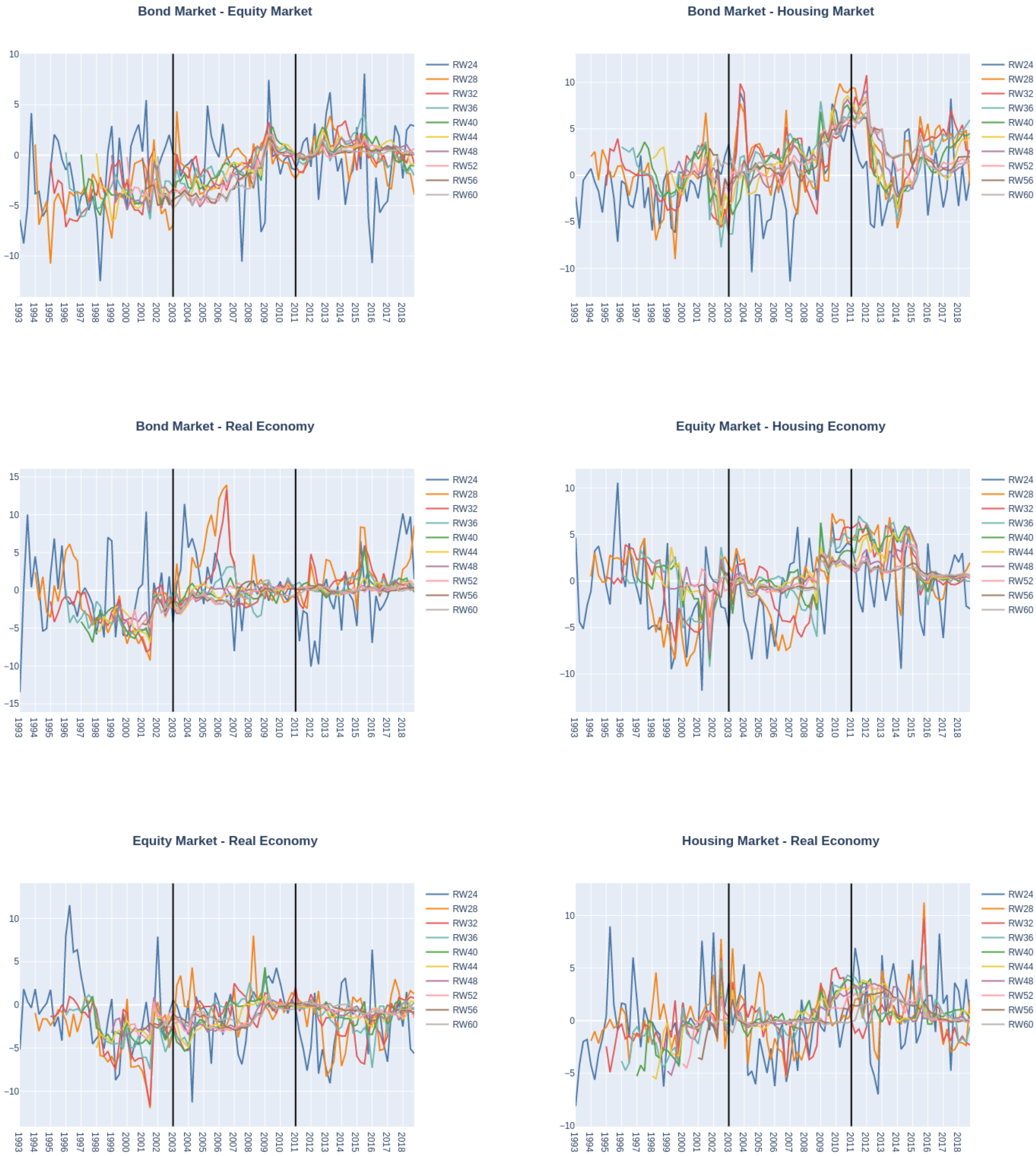

Figure A.5.3

Sensitivity of Rolling Window: Net Pairwise Spillovers — Volatilities

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The charts only display net pairwise spillovers in one direction for any given variable pair. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic growth volatilities are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, VAR models of order 4 and various sized rolling windows (24 to 60-quarters).

Appendix B

Dynamics of Connectedness: Returns

B.1 Preliminary Results — Returns

Table B.1.1
Summary Descriptive Statistics & Correlation Matrix — Returns

	BON	EQU	HOU	GDP
BON	1			
EQU	0.119	1		-
HOU	0.244	0.010	1	
GDP	0.097	-0.006	0.124	1

(a) Correlation Matrix — Returns

	BON	EQU	HOU	GDP
Mean	-0.010	0.005	0.016	0.008
Median	-0.008	0.017	0.012	0.007
Max.	0.312	0.216	0.100	0.029
Min.	-0.313	-0.549	-0.0340	-0.013
Std. dev.	0.094	0.085	0.025	0.006
Skew	0.139	-2.335	0.841	0.212
Kurt.	4.499	16.675	4.246	4.440
J-B.	12.402***	1113.770***	23.378***	12.012***

(b) Summary Descriptive Statistics — Returns

Table contains the correlation matrix (a) and summary descriptive statistics (b) of the representative variables used in spillover estimation in Chapter 3. Rejection of the joint null hypothesis for the Jarque-Bera (J-B.) test that skewness and excess kurtosis is zero is denoted by the following levels of statistical significance: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Each observation in the financial series (i.e. BON, EQU and HOU) has been transformed into a rate of return in percentage format. Each observation in the real economy series (i.e. GDP) has been transformed into a rate of growth in percentage format. The variable "BON" represents the Australian bond market using 10-year Australian government bond yield data. The variable "EQU" represents the Australian equity market using All Ordinaries index data. The variable "HOU" represents the Australian housing market using Established House Price Index data. the variable "GDP" represents the Australian real economy using GDP data. All variables are at the quarterly frequency for the full sample period of 1995Q1 to 2018Q4. A full description of data is provided in Section 3.2 with further details in Table A.2.1 of Appendix A.

Table B.1.2
Augmented Dickey-Fuller (ADF) Tests — Returns

Type of ADF Test	BON	EQU	HOU	GDP
Intercept	-11.186***	-12.393***	-4.768***	-9.968***
Trend & Intercept	-11.140***	-12.343***	-4.810***	-10.078***
None	-11.094***	-12.402***	-4.059***	0.071*

Table displays Augmented Dickey-Fuller tests for stationarity for each of the previously specified representative variables used in return spillover estimation in Appendix B. Rejection of the null hypothesis that a unit root is present in the series is denoted by the following levels of statistical significance: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. All variables are at the quarterly frequency for the full sample period of 1995Q1 to 2018Q4. A full description of data is provided in Section 3.2 with further details in Table A.2.1 of Appendix A.

B.2 Static Analysis of Connectedness — Returns

Table B.2.1
Static Connectedness Table — Returns

	Real Economy	Bond Market	Equity Market	Housing Market	Directional *FROM* Others
Real Economy	95.320	0.510	2.201	1.970	4.680
Bond Market	0.524	87.520	4.556	7.401	12.480
Equity Market	5.626	3.235	89.893	1.245	10.107
Housing Market	0.972	5.524	2.300	91.204	8.796
Directional *TO* Others	7.122	9.269	9.057	10.616	
Directional Including Own	102.441	96.789	98.950	101.820	*Total* Spillover Index: 9.016%
Net Directional Connectedness	2.441	-3.211	-1.050	1.820	

Table displays the connectedness measures specified in Table 3.1.3 of Section 3.1. All estimates are computed using the rates of return of financial variables (i.e. BON, EQU and HOU) and rates of growth of the real economy variable (i.e. GDP). All figures are expressed in percentage terms. Each cell in the upper-left 4x4 matrix displays the relative contribution of the 'column' variable to the variance of the forecast error for the 'row' variable. The "Directional *FROM* Others" column displays the total forecast error variance portions of the row variables due to shocks from other variables. The "Directional *TO* Others" row displays the total forecast error variance portions of the column variables to the forecast error variance of all other variables. Each cell in the "Directional Including Own" row displays the total forecast error variance portions of a given to the forecast error variance of all other variables and the total forecast error variance attributable to the given variable itself. Each cell in the "*Net* Directional Connectedness" row displays the net difference between the corresponding cells in the "Directional *TO* Others" row and the "Directional *FROM* Others" column. The "*Total* Spillover Index" is the average of all elements in the "Directional *TO* Others" row (or equivalently, the "Directional *FROM* Others" column) multiplied by 100 per cent.

B.3 Dynamic Analysis of Connectedness — Returns

Table B.3.1
Total & Net Pairwise Connectedness Measures — Returns

	TOTAL	BONEQU	BONHOU	BONGDP	EQUHOU	EQUGDP	HOUGDP
FULL SAMPLE							
1995–2018							
Mean	39.974	-0.753	1.698	0.245	1.163	0.753	-0.287
Std. Dev.	8.614	1.698	2.145	2.236	2.160	1.664	2.727
Minimum	19.509	-4.258	-2.866	-4.454	-2.899	-2.494	-8.828
Maximum	55.167	5.711	6.673	7.296	8.034	6.300	4.608
SUBSAMPLE 1							
1995–2002							
Mean	35.485	-0.182	1.207	-0.549	0.096	0.753	-0.865
Std. Dev.	9.164	1.401	1.990	1.427	1.669	2.081	2.844
Minimum	19.509	-2.211	-2.462	-3.411	-2.899	-2.336	-8.828
Maximum	53.018	3.208	4.783	2.312	4.003	6.300	4.608
SUBSAMPLE 2							
2003–2010							
Mean	42.097	-1.155	2.455	1.651	1.014	1.205	-0.655
Std. Dev.	8.380	1.794	2.112	2.461	1.433	1.530	2.975
Minimum	25.461	-4.258	-1.345	-2.574	-1.374	-2.494	-7.269
Maximum	55.167	5.711	6.673	7.296	4.351	4.416	4.397
SUBSAMPLE 3							
2011–2018							
Mean	42.339	-0.922	1.430	-0.367	2.378	0.302	0.659
Std. Dev.	6.174	1.717	2.121	1.981	2.553	1.109	2.002
Minimum	28.590	-4.200	-2.866	-4.454	-1.137	-2.348	-3.324
Maximum	51.761	2.077	4.958	4.293	8.034	2.107	4.283

Table presents summary statistics for the total and net pairwise connectedness measures for the sample period of 1995Q1 to 2018Q4 and specified subsamples. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4.

Table B.3.2
Partial Aggregated Connectedness Measures — Returns

	FULL SAMPLE 1995–2018			**SUBSAMPLE 1 1995–2002**			**SUBSAMPLE 2 2003–2010**			**SUBSAMPLE 3 2011–2018**		
	TO ALL	FROM ALL	NET	TO ALL	FROM ALL	NET	TO ALL	FROM ALL	NET	TO ALL	FROM ALL	NET
MEAN												
Bond Market	10.907	9.717	1.189	8.321	7.844	0.476	13.504	10.553	2.951	10.895	10.754	0.141
Equity Market	13.307	10.638	2.669	11.191	10.161	1.030	13.772	10.398	3.374	14.958	11.356	3.602
Housing Market	6.383	9.530	-3.147	6.027	8.195	-2.168	6.269	10.394	-4.125	6.853	10.002	-3.149
Real Economy	9.377	10.088	-0.711	9.946	9.285	0.662	8.551	10.752	-2.200	9.633	10.227	-0.594
STD. DEV.												
Bond Market	4.502	2.852	3.935	3.458	3.217	2.383	4.401	2.298	3.784	4.006	1.868	4.662
Equity Market	4.157	2.123	3.839	3.851	2.331	3.569	2.649	1.891	2.985	4.752	1.926	4.302
Housing Market	2.875	3.328	3.575	2.698	3.716	3.349	2.690	3.305	3.458	3.149	2.396	3.641
Real Economy	4.302	3.487	3.932	4.180	3.523	3.672	2.820	4.256	3.559	5.387	2.200	4.015
MINIMUM												
Bond Market	2.696	2.872	-6.885	2.756	2.872	-4.113	2.696	4.719	-5.466	5.440	6.468	-6.885
Equity Market	3.361	5.104	-5.312	3.361	6.264	-5.312	9.070	6.735	-4.641	8.541	5.104	-3.100
Housing Market	1.631	2.852	-12.544	1.631	2.852	-12.544	1.983	2.917	-11.611	1.867	5.405	-11.464
Real Economy	3.132	2.223	-14.827	3.900	2.223	-9.506	4.135	5.097	-14.827	3.132	6.798	-7.445
MAXIMUM												
Bond Market	23.028	14.068	11.046	14.184	13.363	4.967	23.028	14.044	11.046	19.482	14.068	8.540
Equity Market	23.411	14.431	11.796	18.146	14.431	5.514	20.994	13.711	11.796	23.411	14.334	11.660
Housing Market	13.665	16.857	8.453	13.408	16.857	8.453	13.592	16.117	1.695	13.665	14.490	2.046
Real Economy	20.533	21.202	8.689	20.533	17.735	8.689	15.173	21.202	2.248	18.748	14.966	6.916

Table presents summary statistics for the partial aggregated connectedness measures for the sample period of 1995Q1 to 2018Q4 and specified subsamples. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4.

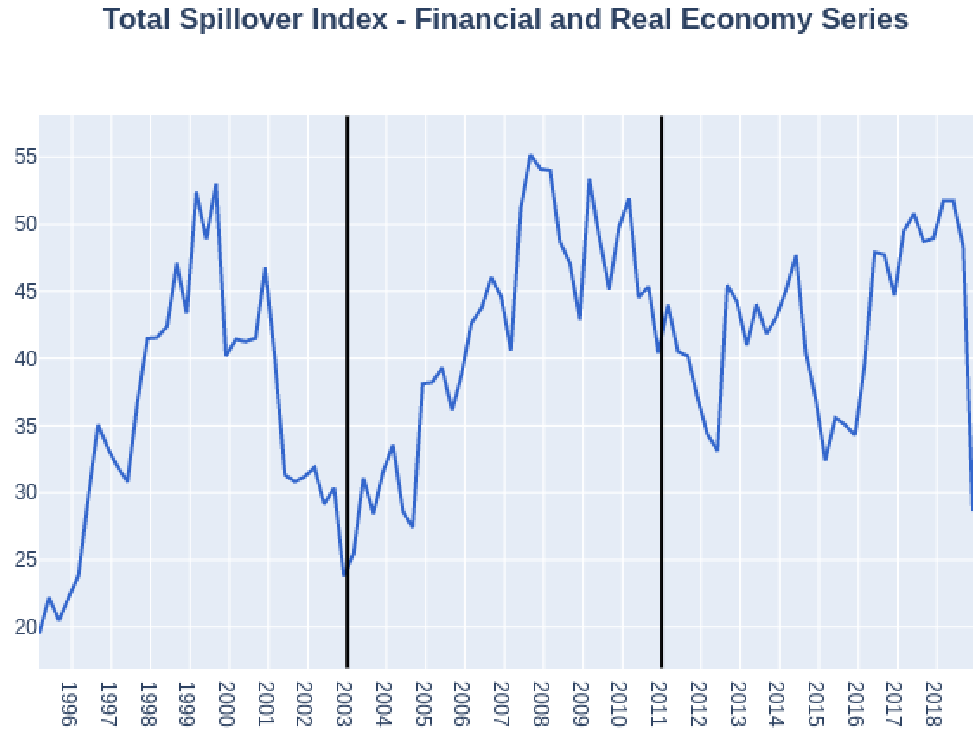

Figure B.3.1
Total Spillover Index — Returns

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return volatilities are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. A full recount of key macro-financial events over the sample period is provided in Table A.2.1 of Appendix A.

Figure B.3.2
Partial Aggregated Connectedness Measures — Returns

Figure plots the spillovers transmitted by each variable to all others (first column), received by each variable from all others (second column) and the net spillovers for each variable to/from all others third column) for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. A full recount of key macro-financial events over the sample period is provided in Table A.2.1 of Appendix A.

Figure B.3.3
Net Pairwise Spillovers Between Variables — Returns

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The charts only display net pairwise spillovers in one direction for any given variable pair. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of order 4. A full recount of key macro-financial events over the sample period is provided in Table A.2.1 of Appendix A.

B.4 Robustness: Order of VAR Model — Returns

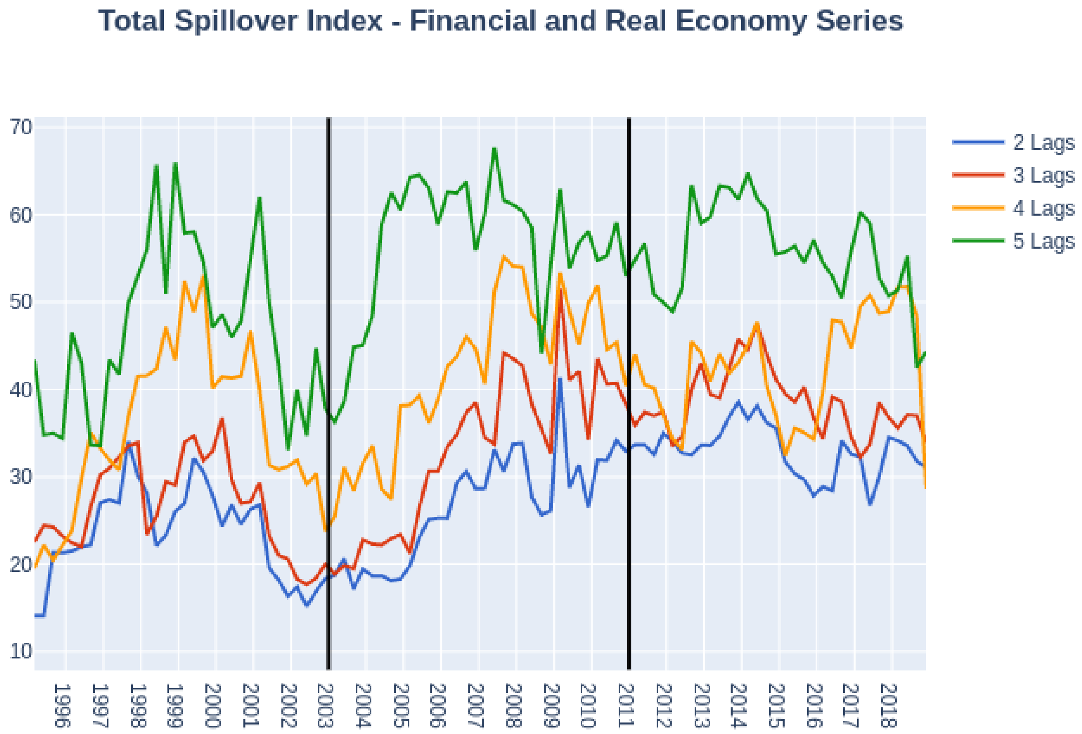

Figure B.4.1
Sensitivity of VAR Order: Total Spillover Index — Returns

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of various orders (2, 3, 4 and 5).

Figure B.4.2
Sensitivity of VAR Order: Partial Connectedness Measures — Returns

Figure plots the spillovers transmitted by each variable to all others (first column), received by each variable from all others (second column) and the net spillovers for each variable to/from all others third column) for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of various orders (2, 3, 4 and 5).

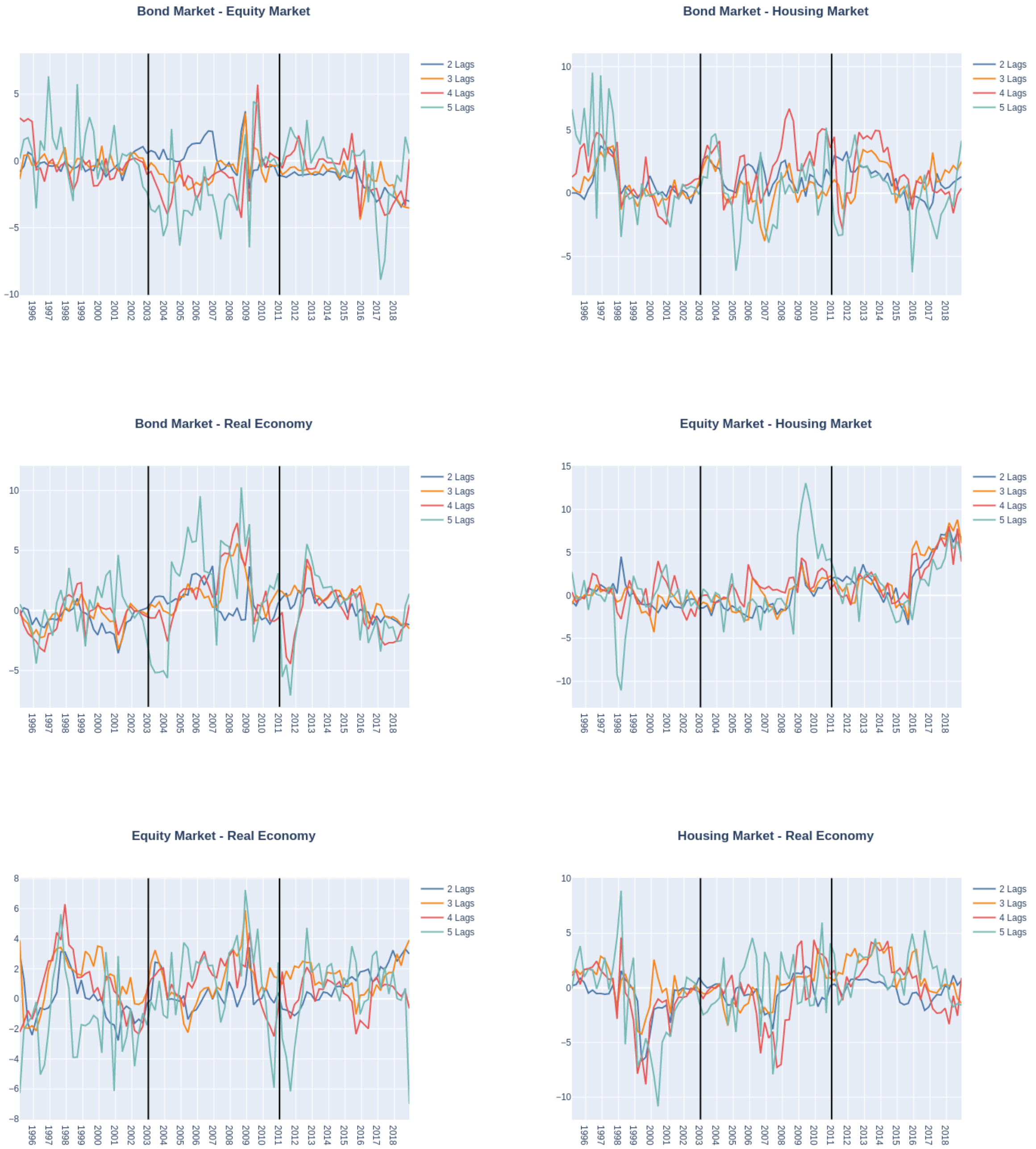

Figure B.4.3
Sensitivity of VAR Order: Net Pairwise Spillovers — Returns

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The charts only display net pairwise spillovers in one direction for any given variable pair. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, 32-quarter rolling window, and VAR models of various orders (2, 3 4 and 5).

B.5 Robustness: Forecast Horizon — Returns

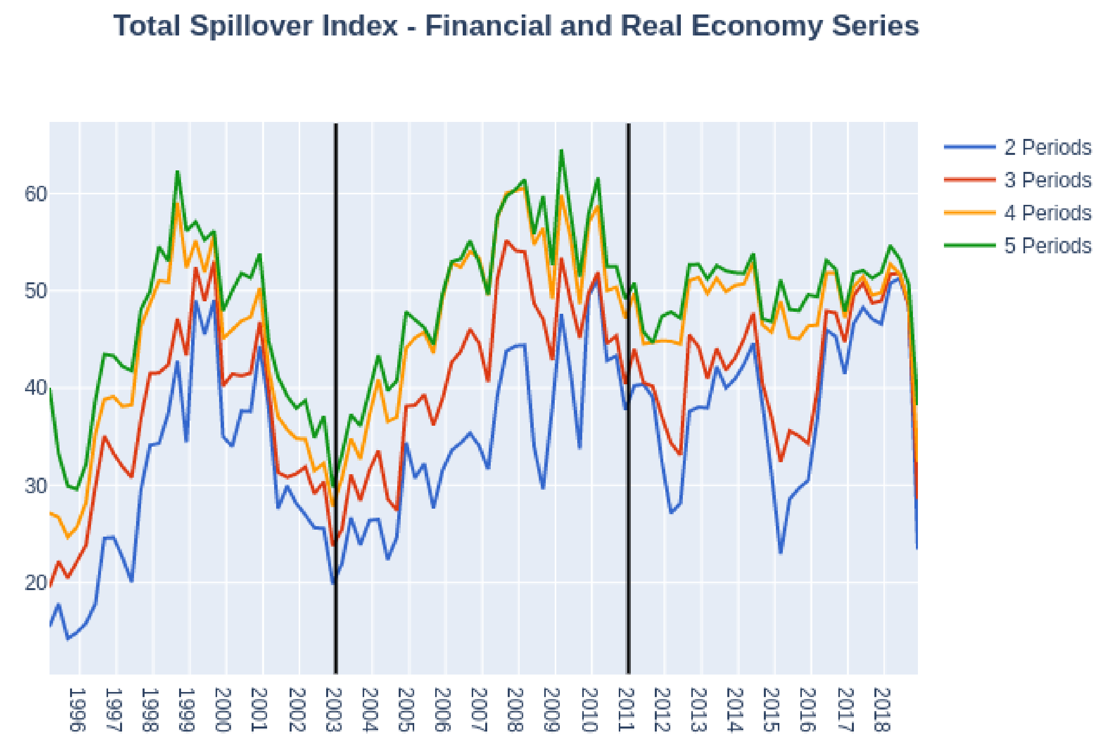

Figure B.5.1
Sensitivity of Forecast Horizon: Total Spillover Index — Returns

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 32-quarter rolling window, VAR models of order 4 and forecast horizon of various sizes (2 to 5 quarters).

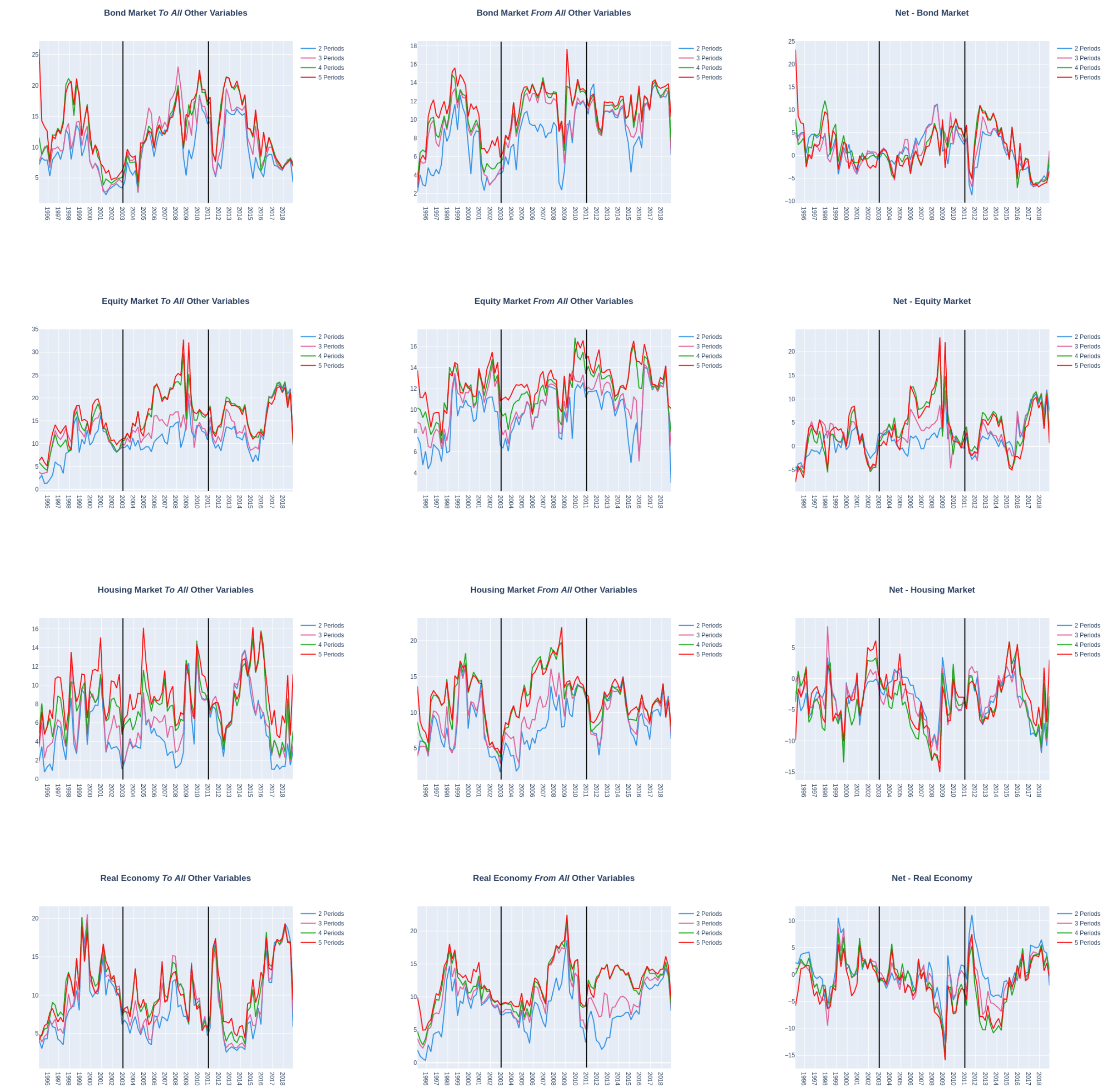

Figure B.5.2
Sensitivity of Forecast Horizon: Partial Connectedness Measures — Returns

Figure plots the spillovers transmitted by each variable to all others (first column), received by each variable from all others (second column) and the net spillovers for each variable to/from all others third column) for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 32-quarter rolling window, VAR models of order 4 and forecast horizon of various sizes (2 to 5 quarters).

Figure B.5.3
Sensitivity of Forecast Horizon: Net Pairwise Spillovers — Returns

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The charts only display net pairwise spillovers in one direction for any given variable pair. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 32-quarter rolling window, VAR models of order 4 and forecast horizon of various sizes (2 to 5 quarters).

B.6 Robustness: Rolling Window — Returns

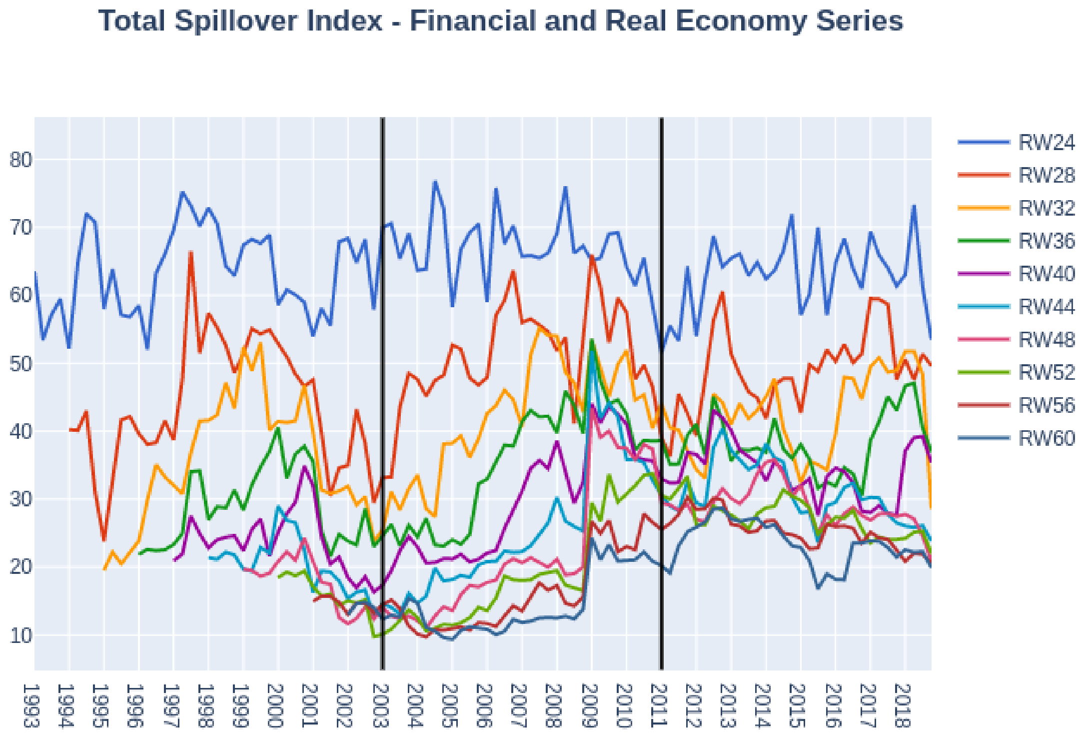

Figure B.6.1
Sensitivity of Rolling Window: Total Spillover Index — Returns

Figure displays the total spillover index for the sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, VAR models of order 4 and various sized rolling windows (24 to 60-quarters).

Figure B.6.2

Sensitivity of Rolling Window: Partial Connectedness Measures — Returns

Figure plots the spillovers transmitted by each variable to all others (first column), received by each variable from all others (second column) and the net spillovers for each variable to/from all others third column) for the full sample period 1995Q1 to 2018Q4. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, VAR models of order 4 and various sized rolling windows (24 to 60-quarters).

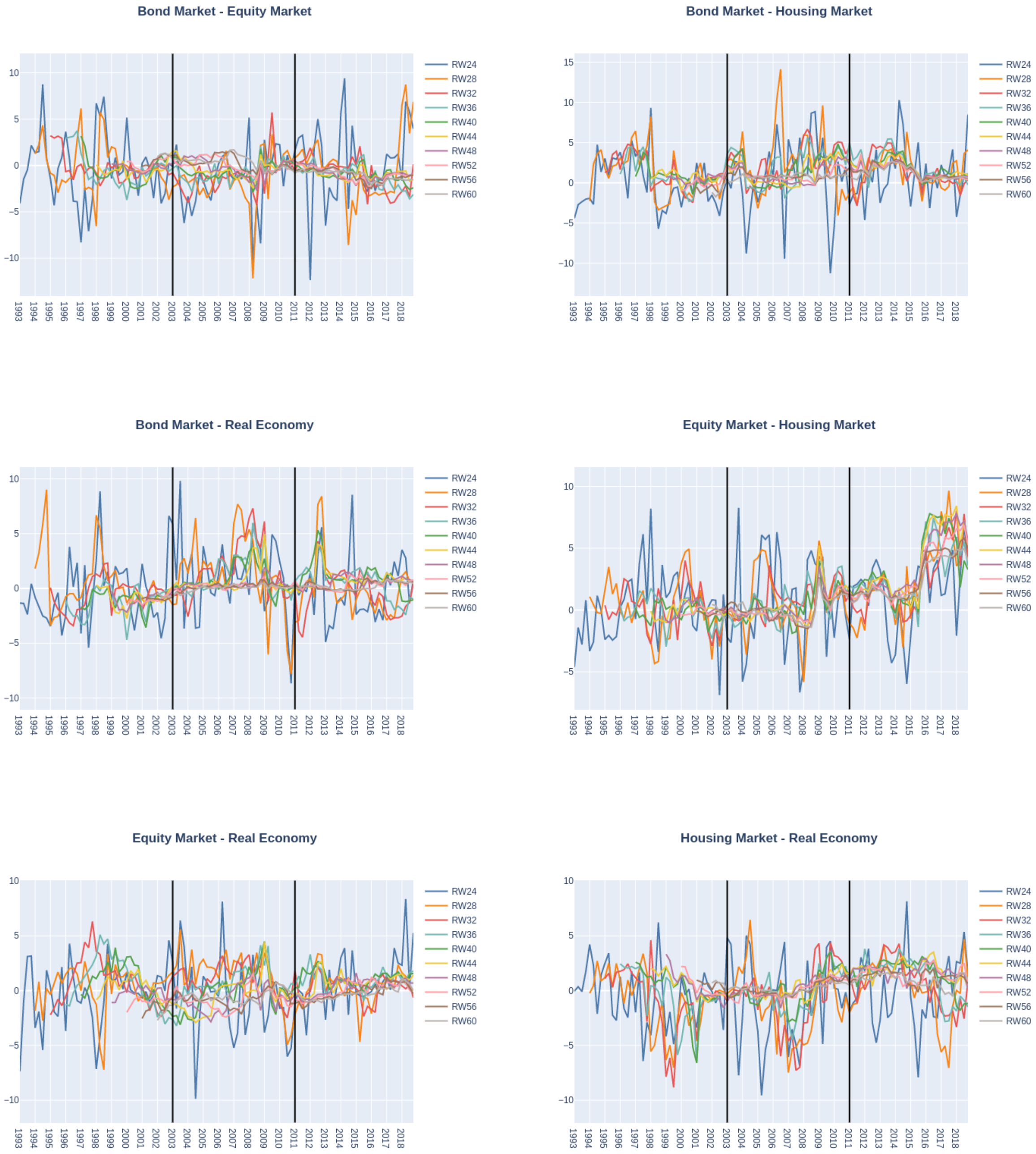

Figure B.6.3
Sensitivity of Rolling Window: Net Pairwise Spillovers — Returns

Figure plots the net pairwise spillover for a given combination of variables, calculated by subtracting the spillovers from the second-listed variable to the first-listed variable by the spillovers from the first-listed variable to the second-listed variable. Pairwise spillovers may be interpreted as the total forecast error variance of the receiving variable at a given forecast horizon that is attributable to shocks in the transmitting variable. The charts only display net pairwise spillovers in one direction for any given variable pair. This is due to the fact that the value of net pairwise spillovers from the All Ordinaries Index (i.e. Equity Market) to GDP is equal to minus one times the net pairwise spillovers from GDP to the All Ordinaries Index. Quarterly logarithmic rates of return are used for the financial All Ordinaries Index, 10-year Australian Government Bond and Established House Price Index series. Quarterly logarithmic rates of growth are used for the real economy series GDP. Values are calculated using a 3-quarter forecast horizon, VAR models of order 4 and various sized rolling windows (24 to 60-quarters).

Appendix C

Determinants of Connectedness

C.1 Data Sourcing

Table C.1.1
Summary of Data Sourcing — Analysis of Historical Determinants

Type of Factor	Factor	Description	Original Frequency	Sample Frequency	Source: Identification Code/s
Macroeconomic	Economic Growth (“GDP”)	GDP by Expenditure, Constant Prices, Seasonally Adjusted	Quarterly	Quarterly	Federal Reserve Economic Data (FRED): NAEXKP01AUQ661S
Macroeconomic	Inflation Rate (“CPI”)	Inflation - CPI, All Groups, Quarterly Change Rate, Seasonally Adjusted	Quarterly	Quarterly	Reserve Bank of Australia (RBA): GCPIAGSAQP
Macroeconomic	Unemployment Rate (“UE”)	Harmonized Unemployment Rate: Total: All Persons for Australia, Seasonally Adjusted, Percentage	Monthly	Quarterly	Federal Reserve Economic Data (FRED): LRUNTTTTAUQ156S
Financial	Consumer Sentiment (“SENT”)	Consumer Sentiment Index - Aggregate for Australia	Monthly	Quarterly	Melbourne Institute: CSI AGGREG DATA SING
Financial	Currency Valuation (“AUD”)	Australia Dollar Trade-Weighted Index	Daily	Quarterly	Reserve Bank of Australia (RBA): FXRTWI
Financial	Equity Market Volatility (“VOL”)	All Ordinaries Index (ASX: XAO)	Daily	Quarterly	Yahoo! Finance: AORD
Financial	Interbank Spread (“INTER”)	Spread Between Quarterly Average Middle Rates of Australia 90-day Bank-Accepted Bill Yield and Australia 90-day Dealer Bill Yield	Monthly, Daily	Quarterly	Datastream: AUOIR072R, S06120
Financial	Term Spread (“TERM”)	Spread Between Quarterly Average Middle Rates of Australia 10-year Government Bond Yield and Australia 90-day Dealer Bill Yield	Daily, Daily	Quarterly	Datastream: S06122, S06120

Table describes the sourcing of the factors used in determinant analyses in Chapter 4. A full description of data is provided in Section 4.2.

C.2 Extended Descriptive Statistics

Table C.2.1
Correlation Matrices — All Factors, All Subsamples

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
CPI	1.000							
GDP	-0.256	1.000						
UE	-0.317	0.157	1.000					
AUD	-0.287	0.062	0.066	1.000				
VOL	-0.288	0.104	-0.063	-0.201	1.000			
SENT	0.023	-0.004	-0.148	0.239	-0.187	1.000		
INTER	0.218	-0.123	0.177	-0.083	0.104	-0.275	1.000	
TERM	-0.157	0.213	0.266	-0.096	-0.158	0.127	-0.088	1.000

(a) Correlation Matrix — All Factors, Subsample 1: 1995–2002

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
CPI	1.000							
GDP	-0.171	1.000						
UE	-0.237	-0.019	1.000					
AUD	0.048	0.210	0.393	1.000				
VOL	-0.055	-0.390	-0.425	-0.439	1.000			
SENT	0.031	0.192	0.347	0.286	-0.729	1.000		
INTER	0.168	0.071	0.176	0.215	-0.270	0.403	1.000	
TERM	-0.331	-0.038	0.774	0.233	-0.245	0.256	0.210	1.000

(b) Correlation Matrix — All Factors, Subsample 2: 2003–2010

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
CPI	1.000							
GDP	-0.314	1.000						
UE	-0.251	0.012	1.000					
AUD	0.119	-0.126	-0.209	1.000				
VOL	-0.319	0.410	0.112	-0.232	1.000			
SENT	0.408	-0.280	-0.286	0.176	-0.334	1.000		
INTER	0.438	-0.097	0.348	-0.066	-0.038	0.082	1.000	
TERM	0.220	0.029	0.353	-0.083	-0.342	0.265	0.303	1.000

(c) Correlation Matrix — All Factors, Subsample 3: 2011–2018

Table contains the correlation matrices of the factors used in determinant analyses in Chapter 4. All variables are at the quarterly frequency for (a) subsample 1 (1995Q1 to 2002Q4), (b) subsample 2 (2003Q1 to 2010Q4) and (c) subsample 3 (2011Q1 to 2018Q4). A full description of data is provided in Section 4.2 with further details in Table C.1.1 of Appendix C.

Table C.2.2
Extended Summary Descriptive Statistics — All Factors, Full Sample & Subsamples

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
Mean	0.624	0.008	6.022	6.53E-05	0.006	104.606	-4.08E-0.7	0.005
Median	0.600	0.007	5.722	7.08E-04	0.006	103.413	-1.43E-06	0.006
Max.	3.800	0.029	8.766	0.009	0.019	120.240	7.35E-05	0.023
Min.	-0.300	-0.005	4.087	-0.013	0.003	85.794	-6.42E-05	-0.015
Std. Dev.	0.515	0.005	1.209	0.004	0.002	7.795	2.27E-05	0.008
Skew.	2.414	0.776	0.803	-0.602	2.226	0.023	0.151	-0.360
Kurt.	16.347	5.182	2.827	3.877	10.926	2.627	3.639	2.823
J.B.	805.881***	28.680	10.428***	8.868**	330.572***	0.565	1.995	2.203

(a) Extended Summary Descriptive Statistics — All Factors, Full Sample: 1995–2018

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
Mean	0.666	0.009	7.415	-2.28E-04	0.006	105.206	-1.12E-06	0.008
Median	0.600	0.008	7.229	4.86E-04	0.006	104.253	-4.27E-06	0.010
Max.	3.800	0.029	8.766	8.60E-03	0.011	115.677	5.19E-05	0.023
Min.	-0.300	-0.004	5.990	-0.009	0.004	97.070	-4.39E-05	-0.008
Std. Dev.	0.720	0.007	0.930	0.004	0.002	5.229	2.29E-05	0.007
Skew.	2.559	0.710	0.032	-0.098	1.247	0.373	0.324	-0.266
Kurt.	12.428	3.649	1.443	2.549	4.935	2.242	2.419	2.632
J.B.	153.437***	3.248	3.237	0.323	13.288***	1.506	1.009	0.559

(b) Extended Summary Descriptive Statistics — All Factors, Subsample 1: 1995–2002

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
Mean	0.694	0.007	5.065	0.001	0.007	108.259	-1.44E-0.6	0.002
Median	0.600	0.007	5.100	0.002	0.006	112.084	-2.65E-06	0.002
Max.	1.500	0.018	6.056	0.009	0.019	120.240	7.35E-05	0.017
Min.	-0.100	-0.005	4.087	-0.013	0.003	85.794	-5.48E-0.5	-0.015
Std. Dev.	0.419	0.005	0.571	0.005	0.004	10.512	2.35E-05	0.008
Skew.	-0.194	-0.095	-0.061	-1.212	1.782	-0.930	0.671	-0.209
Kurt.	2.521	3.506	1.986	4.975	6.449	2.679	5.221	2.331
J.B.	0.505	0.390	1.390	13.032***	32.807***	4.747*	8.979**	0.830

(c) Extended Summary Descriptive Statistics — All Factors, Subsample 2: 2003–2010

	CPI	GDP	UE	AUD	VOL	SENT	INTER	TERM
Mean	0.513	0.006	5.584	-0.001	0.006	100.352	1.34E-06	0.005
Median	0.500	0.007	5.608	-6.91E-05	0.005	100.263	8.15E-07	0.006
Max.	1.300	0.013	6.258	0.004	0.010	108.172	3.67E-05	0.015
Min.	-0.100	-0.003	4.963	-0.009	0.004	93.112	-6.42E-05	-0.012
Std. Dev.	0.318	0.004	0.372	0.003	0.002	3.940	2.24E-05	0.006
Skew.	0.520	-0.489	0.042	-0.789	0.947	0.183	-0.621	-0.621
Kurt.	3.159	3.035	2.047	3.481	3.284	2.441	3.419	3.197
J.B.	1.476	1.276	1.220	3.627	4.895*	0.597	2.293	2.108

(d) Extended Summary Descriptive Statistics — All Factors, Subsample 3: 2011–2018

Table contains extended summary descriptive statistics of the factors used in determinant analyses in Chapter 4. Rejection of the joint null hypothesis for the Jarque-Bera (J-B.) test that skewness and excess kurtosis is zero is denoted by the following levels of statistical significance: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. The set of variables include both real economy (inflation-"CPI", GDP growth-"GDP", and unemployment-"UE") and financial (AUD return-"AUD", equity market volatility-"VOL", consumer sentiment-"SENT", interbank spread-"INTER" and term spread-"TERM") series. Prior to computing summary statistics, all variables excluding the consumer sentiment index ("SENT") were converted from percentage format to decimal format. The summary statistics computed for the consumer sentiment index are obtained from raw figures. All variables are at the quarterly frequency for the full sample period (1995Q1 to 2018Q4), subsample 1 (1995Q1 to 2002Q4), subsample 2 (2003Q1 to 2010Q4) and subsample 3 (2011Q1 to 2018Q4). A full description of data is provided in Section 4.2 with further details in Table C.1.1 of Appendix C.

C.3 Explanatory Power of Individual Factors — Returns

Table C.3.1
Explanatory Power of Individual Factors for Connectedness Measures — Returns, Full Sample: 1995–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.001	0.027	0.213	0.000	0.004	0.036	0.003	0.020
Net Spillovers								
Net Bond	0.036	0.000	0.004	0.000	0.010	0.024	0.036	0.018
Net Equity	0.004	0.044	0.127	0.000	0.052	0.006	0.003	0.003
Net Housing	0.016	0.001	0.019	0.015	0.000	0.003	0.002	0.025
Net Real Economy	0.000	0.021	0.020	0.013	0.011	0.080	0.009	0.002
Spillovers to All Others								
Bond to All Other	0.008	0.002	0.078	0.007	0.022	0.006	0.077	0.038
Equity to All Other	0.000	0.039	0.260	0.001	0.023	0.004	0.000	0.015
Housing to All Other	0.008	0.030	0.012	0.011	0.003	0.046	0.001	0.001
Real Economy to All Other	0.003	0.001	0.010	0.000	0.004	0.010	0.026	0.000
Spillovers from All Others								
Bond from All Other	0.012	0.005	0.181	0.008	0.005	0.007	0.015	0.007
Equity from All Other	0.003	0.006	0.225	0.002	0.001	0.000	0.008	0.025
Housing from All Other	0.001	0.038	0.054	0.001	0.004	0.020	0.005	0.015
Real Economy from All Other	0.002	0.014	0.075	0.008	0.034	0.181	0.011	0.005
Pairwise Spillovers								
Bond - Equity	0.034	0.019	0.102	0.001	0.048	0.006	0.003	0.006
Bond - Housing	0.009	0.000	0.000	0.010	0.000	0.001	0.076	0.013
Bond - Real Economy	0.029	0.006	0.022	0.007	0.001	0.075	0.001	0.012
Equity - Housing	0.008	0.043	0.039	0.000	0.058	0.001	0.001	0.008
Equity - Real Economy	0.014	0.003	0.042	0.001	0.000	0.057	0.011	0.065
Housing - Real Economy	0.020	0.013	0.001	0.006	0.022	0.005	0.031	0.027

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table C.3.2

Explanatory Power of Individual Factors for Connectedness Measures — Returns, Subsample 1: 1995–2002

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.003	0.011	0.295	0.008	0.015	0.256	0.031	0.138
Net Spillovers								
Net Bond	0.013	0.049	0.628	0.018	0.061	0.003	0.036	0.178
Net Equity	0.000	0.010	0.278	0.001	0.049	0.201	0.006	0.239
Net Housing	0.000	0.001	0.009	0.000	0.018	0.003	0.004	0.015
Net Real Economy	0.008	0.005	0.021	0.016	0.210	0.107	0.063	0.005
Spillovers to All Others								
Bond to All Other	0.068	0.031	0.239	0.015	0.003	0.232	0.012	0.013
Equity to All Other	0.004	0.019	0.509	0.026	0.014	0.184	0.000	0.145
Housing to All Other	0.000	0.065	0.188	0.000	0.012	0.085	0.119	0.188
Real Economy to All Other	0.000	0.007	0.432	0.002	0.135	0.051	0.065	0.092
Spillovers from All Others								
Bond from All Other	0.029	0.000	0.030	0.000	0.025	0.290	0.003	0.060
Equity from All Other	0.010	0.016	0.448	0.060	0.001	0.073	0.010	0.022
Housing from All Other	0.000	0.024	0.056	0.000	0.031	0.028	0.085	0.157
Real Economy from All Other	0.004	0.001	0.380	0.003	0.000	0.306	0.004	0.079
Pairwise Spillovers								
Bond - Equity	0.001	0.013	0.353	0.008	0.000	0.055	0.020	0.038
Bond - Housing	0.032	0.024	0.692	0.005	0.023	0.057	0.079	0.061
Bond - Real Economy	0.006	0.013	0.074	0.141	0.054	0.254	0.002	0.099
Equity - Housing	0.016	0.001	0.014	0.011	0.128	0.022	0.018	0.134
Equity - Real Economy	0.002	0.005	0.147	0.000	0.013	0.311	0.001	0.138
Housing - Real Economy	0.008	0.005	0.220	0.000	0.104	0.027	0.083	0.030

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for subsample 1 (1995Q1 to 2002Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table C.3.3

Explanatory Power of Individual Factors for Connectedness Measures — Returns, Subsample 2: 2003–2010

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.000	0.007	0.112	0.006	0.009	0.203	0.032	0.015
Net Spillovers								
Net Bond	0.152	0.003	0.493	0.000	0.041	0.139	0.029	0.312
Net Equity	0.017	0.005	0.009	0.010	0.224	0.286	0.062	0.001
Net Housing	0.136	0.005	0.267	0.050	0.009	0.038	0.085	0.198
Net Real Economy	0.013	0.040	0.005	0.129	0.202	0.307	0.117	0.002
Spillovers to All Others								
Bond to All Other	0.079	0.003	0.298	0.028	0.012	0.014	0.141	0.123
Equity to All Other	0.013	0.000	0.062	0.005	0.073	0.346	0.000	0.005
Housing to All Other	0.116	0.032	0.044	0.011	0.003	0.062	0.002	0.113
Real Economy to All Other	0.025	0.015	0.041	0.034	0.027	0.141	0.000	0.036
Spillovers from All Others								
Bond from All Other	0.002	0.028	0.000	0.089	0.200	0.082	0.155	0.023
Equity from All Other	0.000	0.004	0.179	0.001	0.047	0.012	0.090	0.017
Housing from All Other	0.005	0.008	0.119	0.019	0.022	0.188	0.072	0.024
Real Economy from All Other	0.000	0.064	0.038	0.037	0.249	0.527	0.092	0.027
Pairwise Spillovers								
Bond - Equity	0.119	0.014	0.294	0.016	0.008	0.000	0.034	0.185
Bond - Housing	0.131	0.000	0.284	0.010	0.024	0.093	0.092	0.150
Bond - Real Economy	0.043	0.002	0.355	0.012	0.113	0.228	0.019	0.277
Equity - Housing	0.021	0.071	0.052	0.004	0.017	0.111	0.068	0.126
Equity - Real Economy	0.015	0.004	0.110	0.056	0.185	0.150	0.177	0.202
Housing - Real Economy	0.099	0.060	0.190	0.037	0.003	0.017	0.001	0.261

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for subsample 2 (2003Q1 to 2010Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table C.3.4

Explanatory Power of Individual Factors for Connectedness Measures — Returns, Subsample 3: 2011–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	0.057	0.003	0.009	0.003	0.060	0.254	0.029	0.162
Net Spillovers								
Net Bond	0.104	0.103	0.062	0.001	0.064	0.011	0.100	0.000
Net Equity	0.001	0.081	0.011	0.011	0.051	0.237	0.009	0.109
Net Housing	0.031	0.048	0.127	0.029	0.109	0.311	0.017	0.015
Net Real Economy	0.051	0.213	0.240	0.007	0.047	0.016	0.132	0.052
Spillovers to All Others								
Bond to All Other	0.273	0.089	0.001	0.001	0.122	0.124	0.138	0.010
Equity to All Other	0.014	0.029	0.051	0.026	0.052	0.307	0.001	0.063
Housing to All Other	0.011	0.001	0.221	0.038	0.003	0.036	0.120	0.035
Real Economy to All Other	0.043	0.076	0.054	0.001	0.007	0.002	0.043	0.015
Spillovers from All Others								
Bond from All Other	0.081	0.008	0.166	0.013	0.015	0.160	0.002	0.042
Equity from All Other	0.037	0.017	0.088	0.026	0.009	0.116	0.008	0.001
Housing from All Other	0.136	0.066	0.020	0.001	0.128	0.235	0.077	0.159
Real Economy from All Other	0.010	0.004	0.029	0.003	0.012	0.050	0.004	0.232
Pairwise Spillovers								
Bond - Equity	0.019	0.006	0.031	0.009	0.000	0.095	0.039	0.034
Bond - Housing	0.167	0.073	0.009	0.000	0.085	0.073	0.086	0.000
Bond - Real Economy	0.036	0.317	0.140	0.000	0.083	0.037	0.073	0.016
Equity - Housing	0.000	0.037	0.038	0.025	0.056	0.117	0.038	0.041
Equity - Real Economy	0.106	0.265	0.050	0.004	0.096	0.425	0.088	0.279
Housing - Real Economy	0.006	0.012	0.208	0.011	0.000	0.077	0.075	0.000

Table reports R-squared values as a representation of the explanatory power for each factor. Explanatory power is estimated by regressing the relevant connectedness measure on a constant term and a single one of the macroeconomic and financial explanatory variables using simple ordinary least squares (OLS). Regressions are estimated for subsample 3 (2011Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

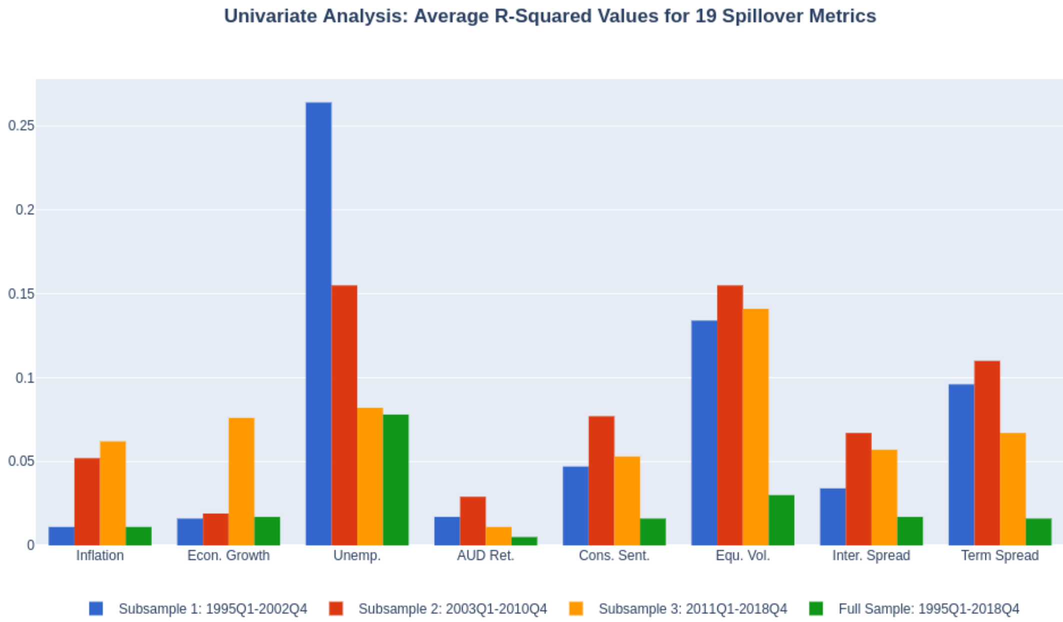

Figure C.3.1
Univariate Regression Approach: Comparative Analysis of Explanatory Power, Average R-squared Values — Returns

Figure displays the average R-squared values associated with the 19 univariate regressions conducted for each variable within each sample period. The blue bars provide results for subsample 1 (1995Q1 to 2002Q4). The red bars provide results for subsample 2 (2003Q1 to 2010Q4). The yellow bars provide results for subsample 3 (2011Q1 to 2018Q4). The green bars provide results for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

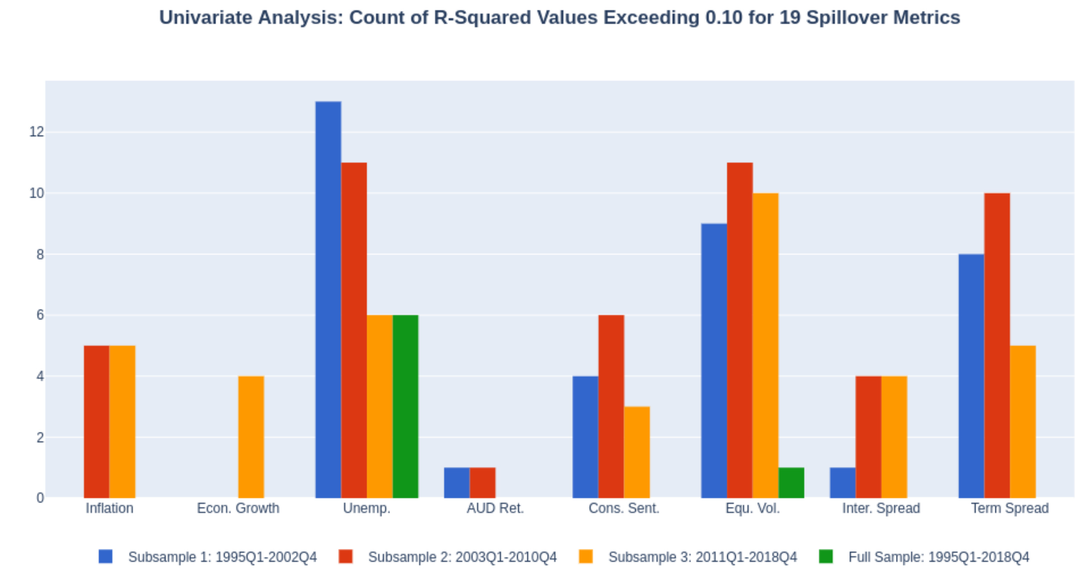

Figure C.3.2
Univariate Regression Approach: Comparative Analysis of Explanatory Power, Count of *R*-squared Values — Returns

Figure displays the number of occasions the R-squared values associated with the 19 univariate regressions conducted for each variable within each sample period exceed 0.10. The blue bars provide results for subsample 1 (1995Q1 to 2002Q4). The red bars provide results for subsample 2 (2003Q1 to 2010Q4). The yellow bars provide results for subsample 3 (2011Q1 to 2018Q4). The green bars provide results for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

C.4 Explanatory Power of Groups of Factors — Returns

Table C.4.1
Explanatory Power of Grouped Factors for Connectedness Measures — Returns

	Full Sample: 1995–2018			**Subsample 1: 1995–2002**			**Subsample 2: 2003–2010**			**Subsample 3: 2011–2018**		
	All	Financial	Macro	All	Financial	Macro	All	Financial	Macro	All	Financial	Macro
Aggregate Spillovers												
Total Spillover Index	0.203	0.004	0.204	0.466	0.347	0.290	0.400	0.370	0.033	0.154	0.191	-0.042
Net Spillovers												
Net Bond	0.099	0.072	0.014	0.657	0.160	0.630	0.627	0.458	0.498	0.202	0.049	0.185
Net Equity	0.170	0.005	0.139	0.455	0.274	0.238	0.342	0.240	-0.074	0.161	0.165	0.003
Net Housing	-0.020	-0.001	-0.001	-0.240	-0.139	-0.095	0.528	0.435	0.273	0.215	0.242	0.085
Net Real Economy	0.047	0.050	0.003	0.082	0.185	-0.080	0.219	0.260	-0.023	0.407	0.028	0.455
Spillovers to All Others												
Bond to All Other	0.150	0.132	0.052	0.369	0.137	0.178	0.614	0.366	0.256	0.236	0.212	0.244
Equity to All Other	0.272	-0.017	0.257	0.612	0.174	0.495	0.365	0.348	0.001	0.168	0.190	-0.020
Housing to All Other	0.030	0.007	0.024	0.352	0.310	0.187	0.054	0.115	0.101	0.101	0.046	0.207
Real Economy to All Other	-0.040	-0.017	-0.016	0.483	0.240	0.420	0.157	0.236	-0.034	0.039	-0.076	0.080
Spillovers from All Others												
Bond from All Other	0.219	-0.015	0.183	0.196	0.282	-0.010	0.180	0.153	-0.075	0.262	0.008	0.144
Equity from All Other	0.187	-0.011	0.200	0.385	0.002	0.408	0.432	0.159	0.103	0.111	0.002	0.044
Housing from All Other	0.019	-0.011	0.047	0.101	0.189	-0.014	0.432	0.407	0.036	0.203	0.254	0.126
Real Economy from All Other	0.194	0.143	0.059	0.547	0.252	0.398	0.471	0.491	0.017	0.079	0.099	-0.063
Pairwise Spillovers												
Bond - Equity	0.281	0.054	0.141	0.369	-0.055	0.349	0.320	0.151	0.282	0.046	0.021	-0.010
Bond - Housing	0.038	0.062	-0.022	0.675	0.093	0.670	0.498	0.380	0.273	0.176	0.122	0.144
Bond - Real Economy	0.076	0.065	0.015	0.550	0.400	0.003	0.324	0.336	0.294	0.394	0.000	0.420
Equity - Housing	0.162	0.048	0.063	0.119	0.188	-0.082	0.247	0.314	0.048	0.019	0.055	-0.003
Equity - Real Economy	0.066	0.075	0.019	0.314	0.294	0.094	0.254	0.247	0.023	0.594	0.514	0.310
Housing - Real Economy	0.054	0.039	0.011	0.139	0.109	0.141	0.271	0.272	0.243	0.193	0.004	0.169

Table reports adjusted R-squared values as a representation of the explanatory power of groups of factors: all, financial (i.e. AUD, VOL, SENT, INTER, TERM) and macroeconomic (macro) (CPI, GDP, UE). Explanatory power is estimated by regressing the relevant connectedness measure on a constant and either all factors (financial and macro), only financial or only macro using simple ordinary least squares (OLS). Adjusted R-squared values are obtained from each regression. Regressions are estimated for the full sample period (1995Q1 to 2018Q4), subsample 1 (1995Q1 to 2002Q4), subsample 2 (2003Q1 to 2010Q4) and subsample 3 (2011Q1 to 2018Q4). All variables within the subsets are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

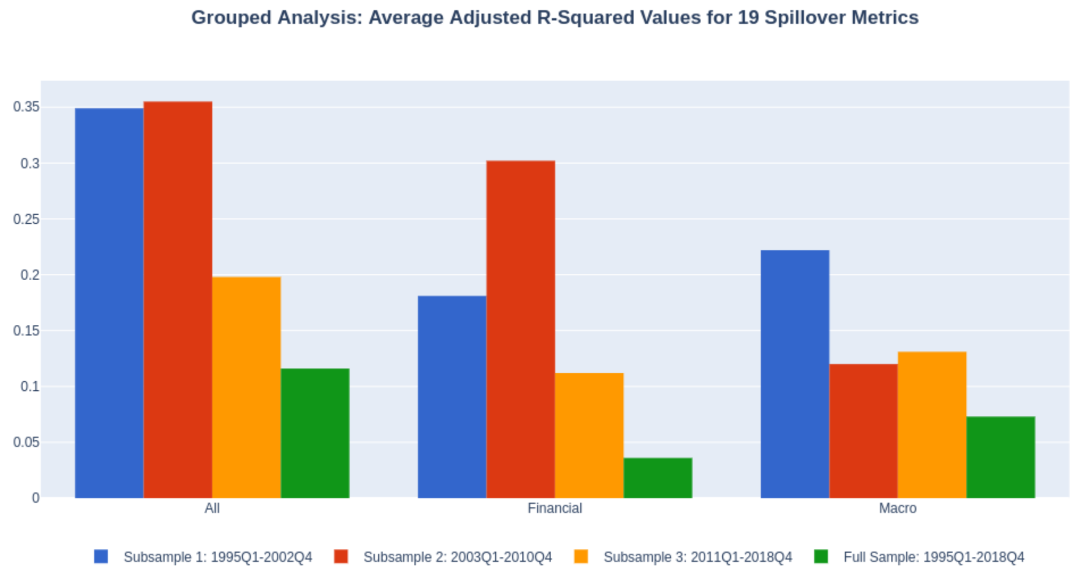

Figure C.4.1
Grouped Regression Approach: Comparative Analysis of Explanatory Power, Average Adjusted *R*-squared Values — Returns

Figure displays the average adjusted R-squared values associated with the 19 grouped regressions conducted for each variable subset within each sample period. The blue bars provide results for subsample 1 (1995Q1 to 2002Q4). The red bars provide results for subsample 2 (2003Q1 to 2010Q4). The yellow bars provide results for subsample 3 (2011Q1 to 2018Q4). The green bars provide results for the full sample period (1995Q1 to 2018Q4). "All" represents the set of all eight previously specified variables. "Financial" represents the set of five previously specified financial variables (i.e. AUD, SENT, VOL, INTER, TERM). "Macro" represents the set of three previously specified macroeconomic variables (i.e. CPI, GDP, UE). All variables within the subsets are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Figure C.4.2
Grouped Regression Approach: Comparative Analysis of Explanatory Power, Counts of Explanatory Dominance — Returns

Figure displays the number of occasions the adjusted R-squared values associated with the 19 grouped regressions conducted for a given subset ("financial" or "macro") exceeds the corresponding adjusted R-squared values for the alternate subset. That is, for example, when the adjusted R-squared value associated with regressing the 'total spillover index' on the financial subset is larger than the adjusted R-squared value associated with regressing the 'total spillover index' on the macro subset. The case where a given subset's adjusted R-squared value exceeds the corresponding value for the alternate subset is termed "explanatory dominance". The blue bars provide counts of explanatory dominance for the subset of financial variables (AUD, SENT, VOL, INTER, TERM). The red bars provide counts of explanatory dominance for the subset of macroeconomic variables (CPI, GDP, UE). All variables within the subsets are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

C.5 Multivariate Analyses — Returns

Table C.5.1
Multivariate Analyses of Connectedness Measures — Returns, Full Sample: 1995–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	-0.980	-0.820	-4.757***	0.381	-0.026	1.414	1.262	1.177
Net Spillovers								
Net Bond	1.722*	0.468	1.688*	0.496	1.857*	2.592**	1.651	-1.582
Net Equity	-1.012	-1.544	-3.974***	0.419	-2.496**	-0.752	-0.038	1.582
Net Housing	-0.879	-0.094	0.661	-1.146	0.734	0.654	-0.429	0.986
Net Real Economy	0.018	0.963	1.152	0.235	-0.356	-2.504**	-1.177	-0.748
Spillovers to all others								
Bond to All Other	-0.132	0.285	-2.217**	0.673	1.718*	1.539	3.195***	-0.886
Equity to All Other	-1.073	-1.099	-5.860***	-0.040	-1.919*	-0.823	0.764	1.580
Housing to All Other	-1.104	-1.613	-1.136	-0.499	0.646	1.850*	0.545	1.179
Real Economy to All Other	0.025	0.355	-0.984	0.531	-0.214	0.756	-1.321	0.662
Spillovers from all others								
Bond from All Other	-2.350**	-0.218	-5.035***	0.254	-0.099	-1.262	2.095**	0.841
Equity from All Other	-0.498	0.222	-4.960***	-0.679	0.100	-0.416	1.449	0.600
Housing from All Other	-0.142	-1.382	-1.692*	0.676	-0.135	1.046	0.922	0.104
Real Economy from All Other	0.014	-0.587	-2.718***	0.492	0.099	3.930***	-0.552	1.798*
Pairwise Spillovers								
Bond - Equity	2.438**	1.226	4.907***	-0.367	3.566***	2.702***	-0.088	-2.664***
Bond - Housing	0.416	0.214	0.711	1.052	0.115	0.739	2.718***	-1.407
Bond - Real Economy	1.742*	-0.123	-0.732	-0.046	1.637	3.219***	0.124	0.262
Equity - Housing	-1.395	-1.868*	-2.992***	0.229	-3.201***	-1.854*	0.740	2.099**
Equity - Real Economy	1.260	0.090	-0.623	0.252	1.325	2.365**	-0.913	-1.167
Housing - Real Economy	-1.717*	-1.239	-0.715	-0.443	-1.222	0.080	2.043**	1.583

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Regressions are estimated for the full sample period (1995Q1 to 2018Q4). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table C.5.2
Multivariate Analyses of Connectedness Measures — Returns, Subsample 1: 1995–2002

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	-0.702	-0.542	-2.837***	-0.458	1.107	2.833***	-0.734	-1.530
Net Spillovers								
Net Bond	1.286	0.866	6.138***	-0.591	-1.256	0.275	0.021	2.080**
Net Equity	-0.675	-0.124	-3.338***	0.401	-1.318	1.942*	0.566	-1.877*
Net Housing	-0.015	-0.282	-0.806	0.405	-0.842	0.260	0.267	1.032
Net Real Economy	-0.210	-0.063	-0.234	-0.335	2.119**	-1.450	-0.579	-0.917
Spillovers to all others								
Bond to All Other	0.424	0.291	3.387***	-0.346	0.870	3.277***	-0.155	0.177
Equity to All Other	-1.103	-0.412	-5.538***	-0.646	-0.915	2.048*	0.499	-1.186
Housing to All Other	-0.228	-1.516	-1.351	-0.143	0.477	1.653	-2.216**	-2.027*
Real Economy to All Other	-0.916	-0.097	-3.851***	-0.163	2.317**	1.165	-0.448	-1.324
Spillovers from all others								
Bond from All Other	-0.333	-0.219	-0.344	0.015	1.493	2.829***	-0.153	-1.000
Equity from All Other	-0.835	-0.433	-4.237***	-1.245	0.028	0.896	0.129	0.195
Housing from All Other	-0.124	-0.666	-0.115	-0.435	1.014	0.768	-1.562	-2.109**
Real Economy from All Other	-0.843	-0.036	-4.380***	0.232	0.093	3.280***	0.200	-0.431
Pairwise Spillovers								
Bond - Equity	1.526	0.334	4.468***	-0.660	0.041	-0.597	-2.025*	-0.158
Bond - Housing	-0.206	0.661	6.370***	-0.120	-0.273	-1.907*	1.516	0.051
Bond - Real Economy	1.626	0.301	-2.238**	-0.425	-1.967*	4.120***	-0.927	3.987***
Equity - Housing	-0.558	0.573	-0.756	-0.832	-1.767*	-1.852*	0.516	-2.071**
Equity - Real Economy	0.125	-0.335	-1.694	0.674	-0.511	3.043***	-0.419	-1.059
Housing - Real Economy	-0.265	0.161	1.702	0.123	-1.486	-1.089	1.075	0.481

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Regressions are estimated for the sample period of 1995Q1 to 2002Q4 (subsample 1). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table C.5.3

Multivariate Analyses of Connectedness Measures — Returns, Subsample 2: 2003–2010

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	-0.196	0.419	-1.874*	2.580**	2.144**	3.654***	1.163	0.833
Net Spillovers								
Net Bond	1.349	-0.033	-3.461***	2.527**	0.694	1.949*	2.024*	-0.216
Net Equity	0.383	1.547	2.424**	0.170	-0.404	3.032***	-0.652	-0.794
Net Housing	-1.135	-0.549	2.398**	-3.364***	-0.359	-1.561	-2.335**	0.448
Net Real Economy	-0.210	-0.505	-1.263	1.104	0.087	-2.027*	1.082	0.279
Spillovers to all others								
Bond to All Other	0.441	0.024	-4.290***	3.333***	2.000*	1.692	2.656**	0.830
Equity to All Other	-0.245	1.544	-0.519	1.422	1.618	4.148***	0.473	0.501
Housing to All Other	-1.080	-0.295	0.288	-0.186	0.781	1.448	-0.128	0.889
Real Economy to All Other	0.705	0.222	-0.169	2.418**	1.176	2.663**	-0.098	-0.355
Spillovers from all others								
Bond from All Other	-0.686	0.055	-1.790*	1.532	1.639	0.194	1.212	1.122
Equity from All Other	-0.808	0.099	-3.746***	1.674	2.658**	1.683	1.451	1.666
Housing from All Other	-0.201	0.172	-1.935*	2.971***	1.265	3.195***	2.064*	0.628
Real Economy from All Other	0.799	0.716	1.197	0.814	0.871	4.323***	-1.224	-0.585
Pairwise Spillovers								
Bond - Equity	0.446	-1.493	-2.748**	0.103	0.466	-1.032	1.164	0.053
Bond - Housing	1.294	0.384	-2.554**	2.552**	0.308	1.834*	2.497**	0.240
Bond - Real Economy	0.565	0.471	-1.311	1.393	0.568	1.982*	-0.161	-0.719
Equity - Housing	-0.410	-0.535	0.446	0.881	0.162	2.141**	1.745*	0.995
Equity - Real Economy	0.975	1.504	1.139	-0.460	-0.375	1.288	-1.596	-1.681
Housing - Real Economy	-0.687	-0.656	1.329	-1.643	-0.118	0.554	-0.105	1.159

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Regressions are estimated for the sample period of 2003Q1 to 2010Q4 (subsample 2). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Table C.5.4

Multivariate Analyses of Connectedness Measures — Returns, Subsample 3: 2011–2018

	Inflation	Econ. Growth	Unemp.	AUD Ret.	Cons. Sent.	Equ. Vol.	Inter. Spread	Term Spread
Aggregate Spillovers								
Total Spillover Index	-0.275	0.621	-0.985	-0.244	0.026	-2.155**	0.854	1.237
Net Spillovers								
Net Bond	1.576	-0.425	2.481**	-0.475	1.767*	-0.328	0.227	-2.000*
Net Equity	-1.211	-1.332	-1.185	0.073	-0.108	-1.433	-0.146	1.842*
Net Housing	0.511	0.137	1.421	0.080	-0.496	2.432**	0.087	-0.325
Net Real Economy	-0.952	2.147**	-3.118***	0.418	-1.559	-0.327	-0.191	0.455
Spillovers to all others								
Bond to All Other	1.864*	0.201	1.239	-0.539	1.318	-1.520	0.742	-1.482
Equity to All Other	-0.926	-0.180	-1.459	0.156	-0.153	-2.341**	0.413	1.055
Housing to All Other	1.108	0.168	2.083**	-0.441	0.340	0.931	0.271	-0.118
Real Economy to All Other	-1.337	0.706	-1.980*	0.151	-0.831	-0.338	0.105	1.601
Spillovers from all others								
Bond from All Other	0.182	1.140	-2.580**	-0.016	-1.101	-1.952*	0.826	1.261
Equity from All Other	0.125	1.869*	-1.019	0.199	-0.135	-2.425**	1.098	-0.920
Housing from All Other	0.855	0.052	1.010	-0.709	1.111	-1.884*	0.258	0.261
Real Economy from All Other	-1.493	-0.762	-0.601	-0.124	-0.016	-0.296	0.368	2.436**
Pairwise Spillovers								
Bond - Equity	1.516	0.756	1.716*	-0.234	0.926	1.039	0.046	-1.699
Bond - Housing	1.748*	0.349	1.885*	-0.621	1.547	-1.441	0.325	-2.149**
Bond - Real Economy	0.386	-2.659**	2.677**	-0.222	1.927*	0.043	0.138	-0.844
Equity - Housing	-1.079	-0.927	-1.160	0.410	0.258	-0.726	-0.427	1.398
Equity - Real Economy	0.003	-2.434**	0.745	-1.324	0.314	-3.057***	0.681	1.834*
Housing - Real Economy	1.177	-0.577	2.677**	0.036	0.993	1.662	-0.070	-0.870

Table reports t-statistics obtained from OLS regressions of macro-financial connectedness measures on a constant term and the entire set of macroeconomic and financial explanatory factors. Levels of statistical significance are indicated by the following: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Regressions are estimated for the sample period of 2011Q1 to 2018Q4 (subsample 3). "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

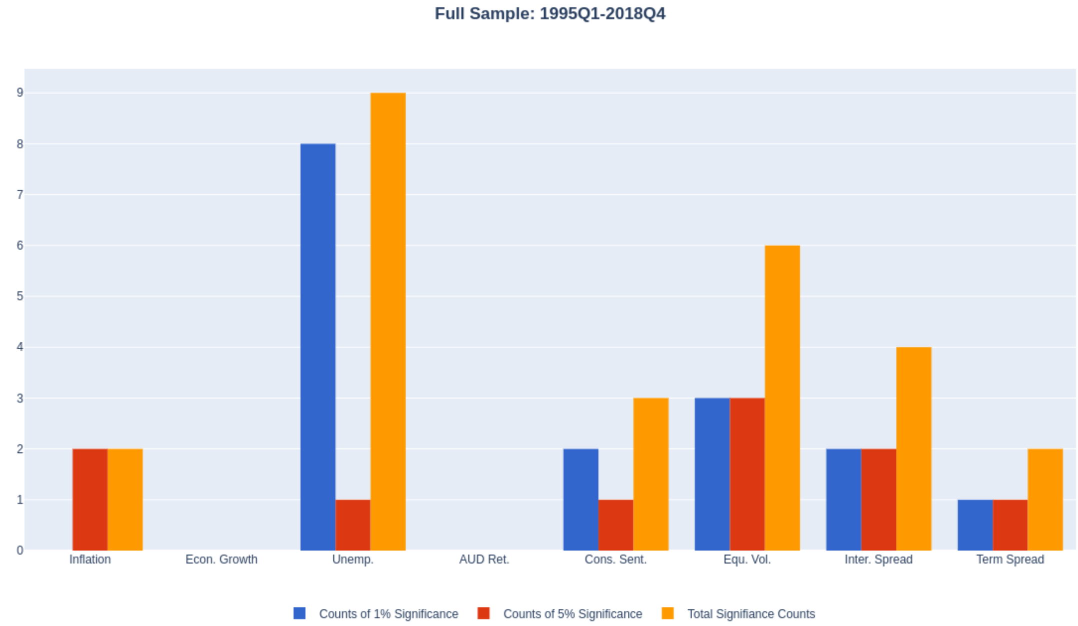

Figure C.5.1
Multivariate Regression Approach: Comparative Analysis of Explanatory Power, Counts of Statistical Significance for Full Sample — Returns

Figure displays the number of occasions a variable is statistically significant in the 19 multivariate regressions conducted within the full sample period (1995Q1 to 2018Q4). The blue bars provide counts of statistical significance at the 1% level. The red bars provide counts of statistical significance at the 5% level (excluding counts of statistical significance at the 1% level). The yellow bars provide the sum of counts of statistical significance represented by the blue and red bars. "Econ. Growth" represents economic growth; "Unemp." represents unemployment; "AUD Ret." represents the return of the Australian dollar; "Cons. Sent." represents consumer sentiment; "Equ. Vol." represents equity market volatility; "Inter. Spread" represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.

Figure C.5.2

Multivariate Regression Approach: Comparative Analysis of Explanatory Power, Counts of Statistical Significance for Subsamples — Returns

Figure displays the number of occasions a variable is statistically significant in the 19 multivariate regressions conducted within each subsample. Subsample 1 spans from 1995Q1 to 2002Q4; subsample 2 spans from 2003Q1 to 2010Q4; subsample 3 spans from 2011Q1 to 2018Q4. The blue bars provide counts of statistical significance at the 1% level. The red bars provide counts of statistical significance at the 5% level (excluding counts of statistical significance at the 1% level). The yellow bars provide the sum of counts of statistical significance represented by the blue and red bars. “Econ. Growth” represents economic growth; “Unemp.” represents unemployment; “AUD Ret.” represents the return of the Australian dollar; “Cons. Sent.” represents consumer sentiment; “Equ. Vol.” represents equity market volatility; “Inter. Spread” represents the interbank spread. All variables are employed at a quarterly frequency with spillover results derived from return and growth rates. A full description of the employed variables may be found in Section 4.2 with descriptive statistics provided in Section 4.3.