Working Paper

Contagion Risk in the Jamaican Financial System

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Abstract

This paper examined contagion risk in the Jamaican financial system through the channel of financial institution network exposures. Shocks to the network pose risks to financial stability particularly in cases where the level of interconnectedness amplifies the impact of the initial shock. To gain insight into the dynamics within the market, this paper first applied network topology techniques to determine the institutions that play an important role in the financial network as well as the evolution of the network structure over time. The network was found to be generally sparse with few institutions having a large number of connections. Additionally, this paper sought to measure the resilience of the system to credit and funding interbank shocks. Simulations indicate a relatively resilient network to contagion risk as institution exposures are less than 100.0 per cent of institution capital in most instances. Results also indicated that the inclusion of foreign institutions to the simulations increased contagion risk due mainly to bank exposures in the form of deposits. Understanding the significance of institutions to systemic risk within the network allows policy makers to tailor liquidity facilities where necessary. Regulatory authorities should focus on monitoring the structure of the network over time and identify what changes occur within the network.

Keywords: network topology, systemic risk, contagion, interbank market

JEL Classification: D85, G21, G28

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1.0 Introduction

The global financial crisis has brought to the fore the need to understand the implications from growing levels of interconnectedness within financial systems. This has led to a proliferation of models for systemic risk and network analysis providing policy makers with tools to assess the vulnerabilities within their respective jurisdictions. Regulators have also become interested in methods for identifying systemically important financial institutions (SIFIs) in order to prepare for possible adverse events.

Systemic risk refers to the possibility that a triggering event such as a bank failure or market disruption could cause widespread disruption of the financial system, including significant difficulties in otherwise viable institutions or markets (ECB, 2010). The rising degree of complexity of the financial system has resulted in accelerated pass-through of disturbances in one segment onto the remaining segments within the system. According to ECB (2010), the impact of systemic risk depends on the collective behavior of financial institutions and their interconnectedness as well as the interaction between financial markets and the macro-economy. This underpins the emphasis of macro-prudential frameworks of financial regulation (ECB 2010-2). Although systemic risk is outside the control of the individual institution, each institution can put measures in place to increase the resilience of the system by managing credit and liquidity risk as well as the exposures to counterparties.

The interconnectedness of the financial system can serve as a shock-amplifier rather than a shock-absorber during periods of stress. This could cause a seemingly robust system to in fact be fragile (ECB 2010). More specifically, shocks that affect highly connected players in the network may have devastating effects on the system in spite of the limited number of institutions impacted by the shock. Hausenblas *et al*. (2012) provide a theoretical framework for the interbank market in normal vis-a-vis stressed times. In periods of market normality, the interbank market ensures that the redistribution of liquidity of banks with surplus liquidity to banks with a shortage of liquidity occurs efficiently. As such the interbank market serves as an absorber of idiosyncratic liquidity shocks since the overall liquidity needed is lower than total amount of liquid assets in the banking sector. Alternatively, in periods of stress, the interbank market becomes a channel for liquidity contagion due to liquidity hoarding by banks and/or a channel for credit risk contagion due to credit losses on interbank exposures. These contagion effects also indicate that in the event of a shock, institutions which have a high share of interbank assets relative to available capital will no longer able to fully repay interbank liabilities. Additionally, the credit and liquidity channel contagion channels can be accompanied by informal channels such as in the event of a bank run or by an asset price channel. This may occur if an excessive supply of banking assets on illiquid markets results in banks incurring losses due to a decrease in the market price of those assets.

This paper examines contagion in the Jamaican financial system through the network exposures. First, network topology is used to determine the structure of the Jamaica's financial institution network, identify significant institutions within the network and track the evolution of the network over time. Secondly, the resilience of the network is assessed by simulating credit as well as credit-plus-funding shocks to the Jamaican financial system, similar to Espinosa-Vega and Solé (2010). This paper also adds to the literature of contagion risk and network analytics within the Caribbean by using funding data and including a liquidity channel. This assessment can assist the Bank of Jamaica (BOJ) in understanding the potential contribution of institutions to systemic risk within the network. Notably, the more interconnected the financial network becomes, the greater the likelihood of shock amplifications. Results indicate that the network is relatively sparse. Five deposit-taking institutions (DTIs) were found to be central to the network based on select measures. Simulations indicate that domestic institutions are resilient to domestic shocks. However, contagion risk increased when foreign institutions were added to the simulation.

The remainder of the paper is organised as follows. Section 2 presents an overview of the relevant literature while section 3 presents the network topology of the Jamaican financial system. Section 4 provides the contagion simulation model while section 5 presents the model results. Finally, section 6 presents the conclusion and policy implications.

2.0 Literature Review

Network analysis provides an avenue through which policy makers are able to assess the characteristics of the financial system in their respective jurisdictions. Further, it also allows for the identification of SIFIs and markets which are critical players in the web of exposures.

Regulators such as the European Systemic Risk Board have been established to map financial risks and their concentration at the system level for macro-prudential supervision of systemic stability. This requires the availability of methods to model inter-linkages and financial institutions' mutual exposures as well as the ability to identify central institutions in the system and detect shock transmission channels. Similarly, the BOJ, in undertaking macro-prudential oversight of the Jamaican financial system, will also need to carry out these types of assessments. According to Allen and Gale (2000) and Freixas et al (2000), an understanding of the structure of financial flows allows for regulators to understand the functioning of the system and therefore be in a position to assess systemic stability and provide liquidity where necessary.

The network analysis literature in finance largely involves the analysis of the topology of networks as well as assessments of the resilience of the network through shock simulations. In particular, Iazetta and Manna (2009) applied network topology to data on deposits of Italian banks from 1990 to 2008 and found that few banks were pivotal to the redistribution of liquidity across the system. Additionally, results indicated that approximately 10 banks in Italy were the most interconnected within the network. Of these institutions, 2 to 3 were among the top 10 banks by volume of traded deposits.

Hausenblas, Kubicova and Lesanovska (2012) analyse the network of the Czech financial system using topology techniques and simulations. Their analysis involved the examination of interbank exposures of domestic banks through the credit, liquidity and asset price channel. Over the period March 2007 to June 2012, it was found that the Czech network was sparse and heterogeneous with connectivity decreasing over time. Measures of importance indicate that few bigger banks were important to the network and many relatively small banks were found to be on the periphery. Hausenblas, et al (2012) concluded that systemic risk in the form of interbank contagion was limited in the Czech banking system based on simulation results. Credit simulations were found to affect no more than two banks in worst-case scenarios and while the introduction of liquidity and asset-price contagion to the model increased the contagion impact, the overall impact was relatively small.

Bach and Atalay (2008) assessed the topology of the daily networks formed by the overnight Federal Funds Market in New York over the period April 1, 1997 to December 29, 2006. They found that the federal funds network was sparse and exhibited the small world phenomenon and was dissassortive. Similar to other networks, most banks were found to have few counterparties and a small number of banks having many counterparties thereby following a fat-tailed distribution.

Espinosa-Vega and Sole (2010) used simulations for cross border financial surveillance by simulating credit and funding shocks for several countries using cross-country interbank exposures from the Bank of International Settlements (BIS). They note that simulations are useful tool for macro-financial surveillance with the benefit of modelling which institutions are affected in subsequent rounds of contagion spill overs. This can potentially assist policy makers with the design of capital surcharges to lessen too-connected-to-fail problems.

Few studies have been conducted in the Caribbean using network analysis. Notwithstanding, there have been on-going efforts by regional groups such as the Regional Financial Stability Committee to develop similar analyses for the region. For the Caribbean, Ogawa, Park, Singh and Thacker (2013) studied the degree of interconnectedness in the financial sector and the vulnerabilities posed by such interconnectedness. This interconnectedness was primarily in the form of large banking groups and financial conglomerates with the four largest banking groups accounting for 75.0 per cent of the banking sector assets in the region. Of the eight CARICOM countries examined, Bahamas and Barbados were found to have the highest inflows of funds due to their significant offshore financial sectors as well as inflows from Europe.

3.0 Network Topology Measures

A network consists of a collection of nodes (financial institutions) and connections between them (which can be directed or undirected links (ECB, 2010-1, 2010-2, Hattori and Suda, 2007)).[2] The links may represent different relationships between nodes in the form of credit relationships, exposures between banks and liquidity flows in the interbank system. An increase in the number of links relative to the number of nodes might signal financial deepening and signal an augmented degree of complexity of the system as a whole. The links between the nodes affect the attributes of the nodes and the structure of the links affect the performance of the system as a

[2] Nodes are also referred to as vertices while links are also referred to as edges.

whole. Therefore to understand the behavior of one node, one must analyse the behavior of many other nodes.

The structure of the interbank market network can be examined by utilising descriptive statistics (such as connectivity, clustering coefficient, etc.) as well as centrality measures (such as degree, closeness, betweenness, eigenvector, etc.) used generally in the network topology literature. *Connectivity*, also referred to as *density*, represents the unconditional probability that two institutions have a link with each other.[3] It is calculated as:

$$p = \frac{m}{n(n-1)} \dots\dots\dots\dots\dots\dots\dots\dots..(1)$$

where *m* is the number of links and n is the credit exposure from one institution to another recorded as neither zero nor 'not available'. An increase in the connectivity implies that the likelihood of connection of two institutions via credit exposures keeps increasing throughout time. For example, connectivity of 0.692 implies that only 69.2 per cent of potential links are used.

As a measure of systemic risk, the *clustering coefficient* measures the level of interconnectedness of a node's neighbor and is the probability that two neighbours with a direct link to a node are linked together. Neighbours of a node *i* are the nodes directly linked to node *i*. The clustering coefficient is calculated as number of links that connect a node's neighbour divided by the total number of possible edges connecting a node's neighbour:

$$C_i = \frac{E_i}{K_i(K_i-1)} \dots\dots\dots\dots\dots..(2)$$

where E_i is the actual number of directed links between node i's K_i neighbours and K_i $(K_i - 1$ is the number of potential links amoung the neighbours of node *i*. A higher clustering coefficient indicates that two banks that have direct links with a third bank have greater probability of being connected to each other. The clustering coefficient of the network is the average of the clustering coefficients of each node in the network. This measures the tendency of a network to cluster. The

[3]Connectivity measures the density of the current network relative to all potential links it could have.

greater the likelihood of connectedness within the network, the greater the potential for clustering within the network.

In addition to the clustering coefficient, centrality indicators provide information on the relevance of the position of a node in a network. As such, they indicate which nodes are considered to be of "systemic importance" and can be used as a macro prudential policy tool for SIFIs. According to Henggeler-Muller (2006), SIFIs have the following centrality characteristics: (i) high degree centrality – many linkages with other institutions within the network, (ii) high closeness centrality – its failure could transmit contagion in a few steps, (iii) high eigenvector centrality – its counterparts are considered relevant within the network, and (iv) high betweenness centrality – there are many paths which pass through the institution. Further, centrality measures can also be used to direct regulatory efforts such as setting limits on institutions' exposures, implementing regulatory fees or capital surcharges or the introduction of an insurance fund financed through institution-specific insurance premia (ECB, 2010).

The dominant centrality measures presented in the literature are degree centrality, closeness centrality, betweenness centrality and eigenvector centrality. *Degree centrality* counts the number of directed links that are connected to a node. There are three main measures of degree centrality, in-degree, out-degree and average degree. *In-degree* measures the liabilities of node and refers to the number of institutions that the node of interest has received funding from. These institutions would become exposed to the node of interest upon default and are reflected by the links that point toward the node. For example, if BNSJ is the node, in-degree refers to the number of institutions that BNSJ owes and that are therefore exposed to BNSJ.

$$K_i^{in} = \sum_i a_{i,j} \dots\dots\dots (3)$$

where $a_{i,j}$ is the credit exposure of institution i to institution j. Conversely, *out-degree* measures the assets of a node and refers to the number of institutions that the node of interest has funded. The node would become exposed to these institutions upon default and is reflected by the links that point away from the node. For example, if BNSJ is the node, out-degree refers to the number of institutions that owe BNS and that therefore BNSJ is exposed to.

$$K_i^{out} = \sum_j a_{i,j} \dots\dots\dots..(4)$$

The *Average Degree* of the network is defined as the number of links divided by the number of nodes, $K = \frac{m}{n}$. Note that average out degree = average in degree.

The *degree distribution* of the in- and out-degrees can be used to distinguish between regular, exponential and scale-free networks. In a regular network, all nodes have the same number of links to and from them. However, an exponential network or random network consists of many nodes with relatively the same number of links while a scale-free network consists of majority nodes with few links and a small number of nodes with a larger number of links. Scale-free networks have highly skewed distributions which follow a power law in the tail of the degree distribution.[4] The degree distribution gives the probability distribution as a function of the degrees *K* of each of the nodes.

$$P(K) = \frac{n_K}{n-1} \dots\dots\dots\dots.(5)$$

where n_K is the number of nodes with *K* links.

Closeness Centrality also referred to as the *average path length* measures the average shortest distance between two nodes. A node is considered important if it is relatively close to all other institutions. This implies that the node has ease of access to a large part of the network. For the network, the average of the closeness centrality measures for each node indicates how many steps on average are required to move from one node to another in a network. This is calculated as follows:

$$C_D = \left[\sum_j d(b_i, b_j)\right]^{-1} \dots\dots\dots\dots(6)$$

[4] The probability of a node possessing K degrees is given by $P(K) = K^{-\propto}$ where $\propto > 0$ is called the power law exponent.

where d is the path distance between institution i and j.

Betweenness centrality measures the number of shortest paths that pass through a node. It is the number of paths between all other paths that pass through the node of interest. A node is more central if it is needed to connect other pairs of nodes. High values indicate that the node has large potential influence to the transfer of funds through the network.[5]

$$C_B = \sum_{j<i} \frac{g_{i,j}(x)}{g_{i,j}} \dots\dots\dots\dots (7)$$

where $g_{i,j}$ is the number of shortest paths from node i to j and $g_{i,j}(x)$ is the number of those paths that go through node x.

Eigenvector centrality measures the quality of the connections within the network. Specifically, it examines whether a particular node is connected to more interconnected nodes in the network relative to less interconnected nodes. This measures the importance of a node’s neighbours and does not only look at the number of neighbours a node has. For example, if NCB has a larger number of links and RBCJ has a small number of links, then FGB would have a higher measure for eigenvector centrality if it were connected to NCB relative to RBCJ.

$$C_E(x) = v_x = \frac{1}{\gamma_{max}(A)} . \sum_{j=i}^{n} a_{j,x} . v_j \dots\dots\dots . (8)$$

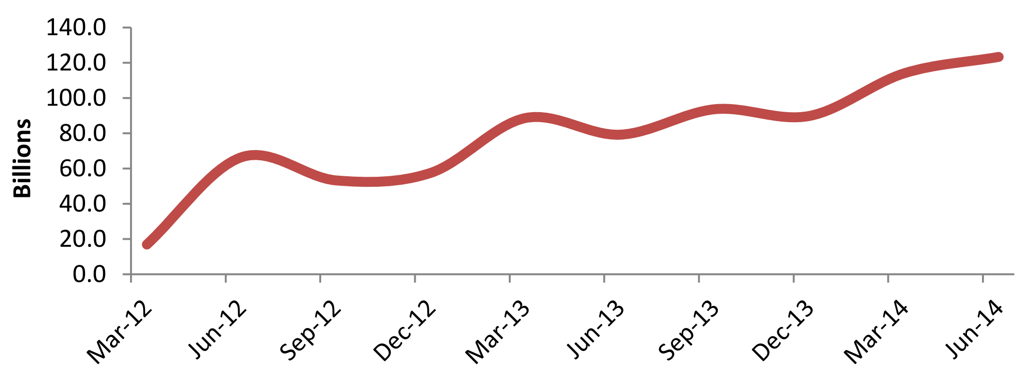
where $v = (v_1, \dots, v_n)^T$ is the eigenvector for maximum eigenvalue $\gamma_{max}(A)$ of the adjacency matrix A.[6]

[5] However, this assumes that funds are transferred through the shortest paths.
[6] See Bonacich and Lloyd (2001) for more information for eigenvector centrality.

3.1 Structure of the Jamaican Interbank Network

For the purposes of this analysis, the Jamaican financial system consists of six commercial banks, two Financial Institution Act (FIA) Licensees or merchant banks, three building societies, the top eleven securities dealers, five life insurance companies and ten general insurance companies and the top five credit unions.[7] In addition to the transactions between each of these institutions, other nodes within the network include other financial institutions not classified as above, foreign institutions as well as public entities. Bilateral interbank credit exposures are based on quarterly interbank assets and liabilities mainly submitted by deposit-taking institutions (DTIs) and securities dealers (SDs).[8] This paper utilizes net credit exposures for the analysis of network topology. Net credit exposures are determined by netting the transactions between two institutions. Negative net credit exposures indicate that a node is a net borrower (received net funding from other nodes) while positive net credit exposures indicate net creditors (provided net funding to other nodes). Positive net credit exposures are useful as from a regulatory standpoint it is important to determine the loss to the institutions that are net creditors if other institutions default on their obligations to those institutions. The time series for net credit liabilities indicates that there has been a steady increase over the period March 2012 to June 2014 (see Figure 1).

Figure 1: The evolution of net credit in the interbank market



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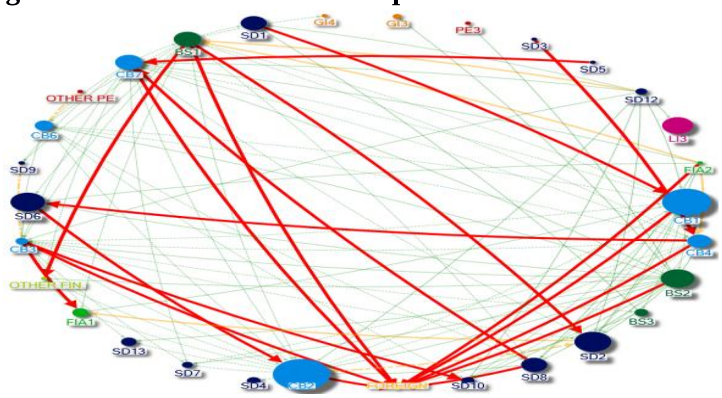
[7] The institutions which form part of the top 11SDs may vary for the period under review.

[8] For the purpose of this analysis, 'secured' items are excluded as these are not considered funding exposure to result in contagion risks.

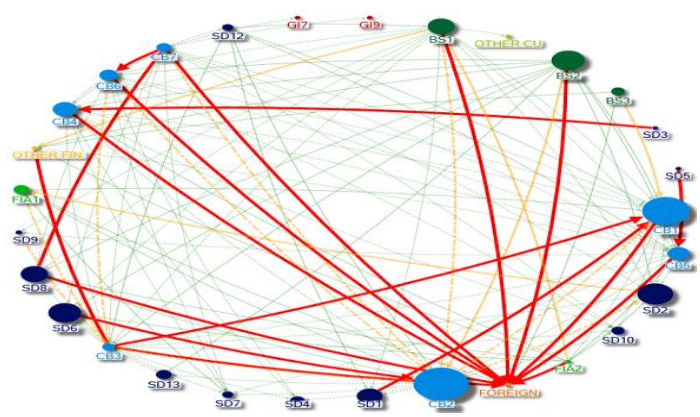
A visualization of the Jamaican Interbank network for June and March 2014 highlights the interconnectedness within the system (see Figure 2 and Figure 3).[9] Of note, the data indicates exposures of several institutions to foreign institutions primarily in the form of deposits. Additionally, the interconnectedness in the network for end-March 2014 is denser than that of the network at end-2013 indicating an increase in the level of activity in the market.

Figure 2: Network model with exposures as at end-June 2014



Note: Solid red links denote net credit exposures >10 per cent of institution capital, Dash-dot yellow edges denote net credit exposures greater than 5 per cent but less than 10 per cent of institution capital. Dotted green edges denote net credit exposures < 5 per cent of institution capital. Nodes are weighted by asset size. Light blue nodes indicate commercial banks, dark green indicate building societies, green nodes indicate FIAs, dark blue nodes indicate SDs, red indicates general insurance companies, yellow indicates life insurance companies, light green indicates credit unions and orange indicates other domestic financial institutions, foreign institutions.

Figure 3: Network model with exposures as at end-March 2014

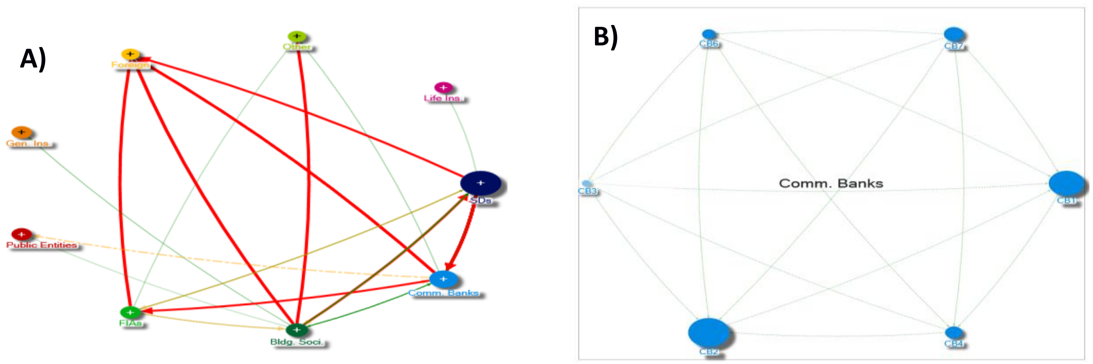


Note: Solid red links denote net credit exposures >10 per cent of institution capital, Dash-dot yellow edges denote net credit exposures greater than 5 per cent but less than 10 per cent of institution capital. Dotted green edges denote net credit exposures < 5 per cent of institution capital. Nodes are weighted by asset size. Light blue nodes indicate commercial banks, dark green indicate building societies, green nodes indicate FIAs, dark blue nodes indicate SDs, red indicates general insurance companies, yellow indicates life insurance companies, light green indicates credit unions and orange indicates other domestic financial institutions, foreign institutions.

[9] The NodeXL - Network Overview, Discovery and Exploration - add-in for Microsoft Excel developed by the Social Media Research Foundation was used to provide visualization and network statistics. For more information on NodeXL, see Smith, *et al* (2009).

In addition to analysis of individual institutions, network analysis can be applied to groups. The Jamaican network was also assessed on the sector level and on the financial group level. A visualisation of the sectoral network indicates that commercial banks, merchant banks, securities dealers and building societies are largely exposed to foreign institutions (see Figure 4B). This is mainly in the form of deposits with these overseas institutions, which include parent companies. Additionally, commercial banks are also net credit exposed to merchant banks while securities dealers are net credit exposed to commercial banks. This assessment can also be extended to visualize the intra-sector network. Of note, only the commercial bank network exhibited significant interconnectedness (see Figure 4A and B).

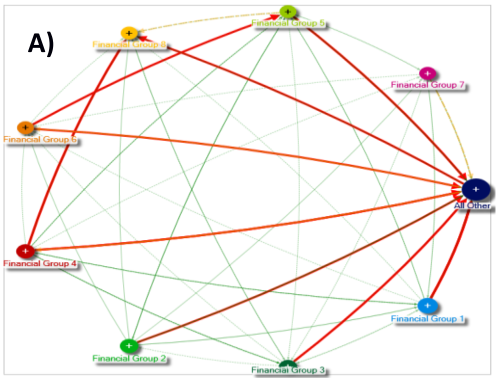
Figure 4: Sectoral and Intra-sectoral Networks as at end-June 2014

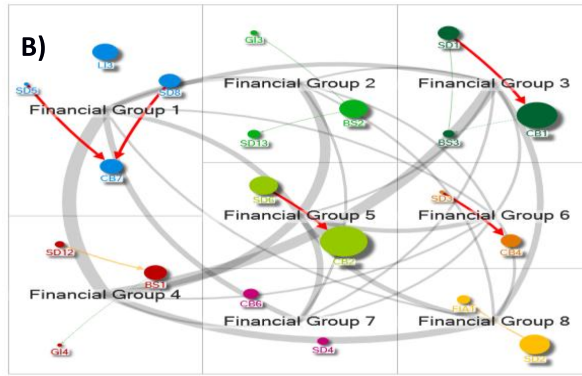


Note: Solid red links denote net credit exposures >10 per cent of institution capital, Dash-dot yellow edges denote net credit exposures greater than 5 per cent but less than 10 per cent of institution capital. Dotted green edges denote net credit exposures < 5 per cent of institution capital.

A visualization of the financial group network indicates high level of interconnectedness in the network (see Figure 5A). Five financial groups are significantly exposed to all other institutions. Additionally, the exposure between financial group 3 and all other institutions exceed 10.0 per cent of capital in both directions. To a lesser extent, several groups are exposed to financial group 5 possibly signaling the group’s importance within the interbank market on a consolidated basis. An assessment at the intra-group level indicates relatively less activity between the institutions in each group (see Figure 5B). Of note, within financial group 1, financial group 3, financial group 5 and financial group 6, the securities dealers are exposed to the commercial banks.

Figure 5: Intra-financial Group Networks as at end-June 2014





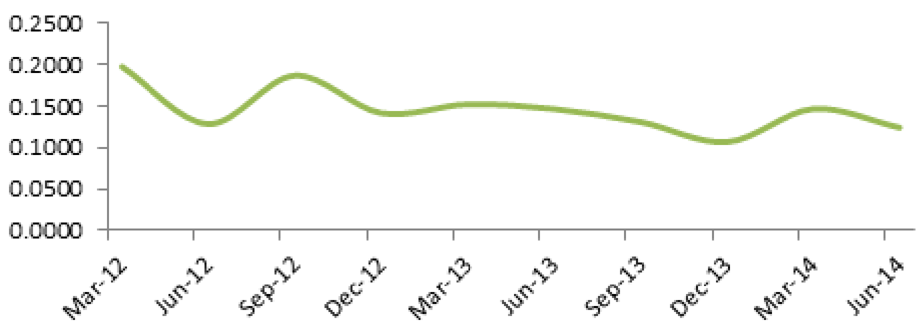
Note: Solid red links denote net credit exposures >10 per cent of institution capital, Dash-dot yellow edges denote net credit exposures greater than 5 per cent but less than 10 per cent of institution capital. Dotted green edges denote net credit exposures < 5 per cent of institution capital.

Although the network diagrams provide a visualisation of the network at specific points in time, it may be difficult to extract trends and tendencies from the network. Statistical measures have been developed to assess the trends and changes in the exposure network based on topological characteristics (Hattori and Suda, 2007).

3.1.1 Connectivity

The connectivity of the Jamaican financial institution network has been on a generally decreasing trend over the time period under review implying a declining likelihood of the connection between two institutions (see Figure 6). Of note, approximately 12.4 per cent of possible links were utilised in June 2014 relative to approximately 19.7 per cent at March 2012. These connections are primarily concentrated between the commercial banks, securities dealers and foreign institutions.

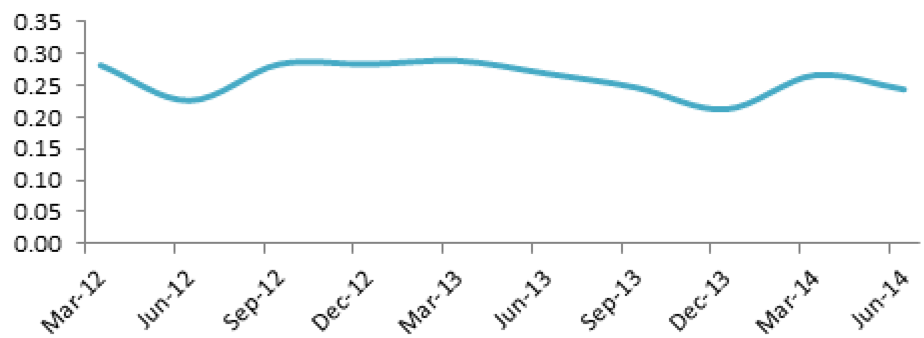
Figure 6: Connectivity of the network



3.1.2 Clustering Coefficient

The clustering coefficient for the network indicates a general decline for most of the review period (see Figure 7). Additionally, the value of the coefficient is relatively low in comparison to other networks indicating one of the properties of a scale-free network highlighted by Markose (2012). In particular, the coefficient was 24.4 per cent at June 2014 which implies that the there is only a 24.4 per cent likelihood that neighbours of a node are connected to each other.

Figure 7: Clustering coefficient of the network



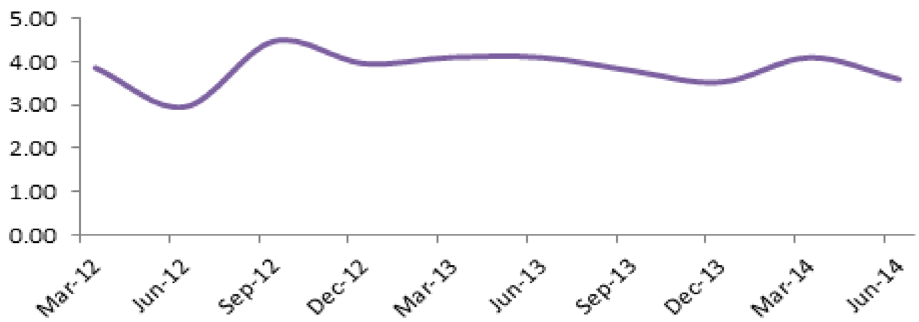
3.1.3 Centrality Measures

Centrality measures indicate that the Jamaican interbank network contains few nodes that are considered central to the network with many nodes being mostly on the periphery. This is evidenced mainly by distribution of the degree, betweenness and to lesser extent eigenvector centrality indicators.

3.1.3.1 Degree Centrality

The time series of the average degree of the network indicates that the average Jamaican financial institution conducted transactions with approximately 4 counterparties over the review period (see Figure 8). However, it is possible that within the network some nodes are highly interconnected within the system relative to others. An analysis of the in-degree and out-degree distributions indicates that the out-degrees exhibit more of characteristics of a scale-free network relative to the in-degrees of the institutions (see appendix). However, due to relatively small number of connections (connectivity = 14.7 per cent), the functions are not as smooth as the theoretical scale-free network. Nevertheless, the distributions illustrate that only a small number of Jamaican financial institutions hold a large number of counterparties similar Iazetta and Manna (2009) for Italy and Boss, et al (2004) for Austria. This implies that shocks that impact these institutions could possibly have a ripple effect on the rest of the network.

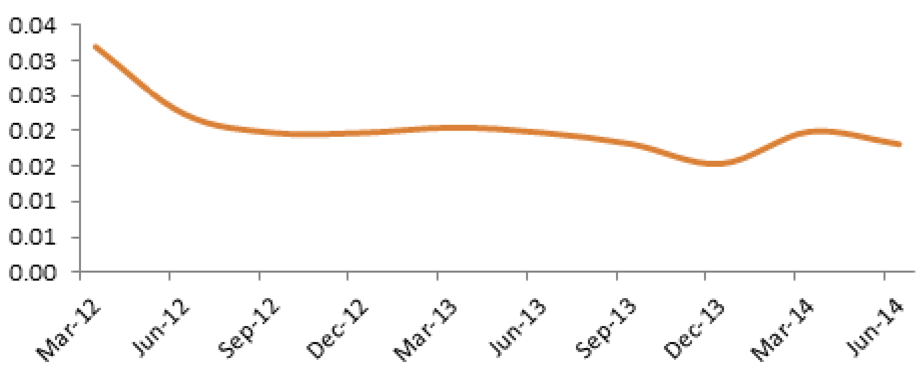
Figure 8: Average degree of the network



3.1.3.2 Closeness, Betweenness and Eigenvector Centrality

The closeness centrality of the network has remained relatively low under the review period within a range of 1.5 per cent to 3.2 per cent over the review period (see Figure 9). This indicates that the institutions are closely connected to each other. Regarding betweenness centrality, a small number of institutions have relatively large centrality measures indicating that the network exhibits scale-free characteristics (see Appendix A). This implies that few nodes are needed by other nodes to connect to institutions within the network. Finally, the Eigenvector centrality measure of the network indicates that few institutions are considered central to the network (see Appendix A).

Figure 9: Closeness centrality



An assessment of the centrality measures for the nodes was conducted similar to Brunnermeier, *et al* (2013) by ranking the nodes within each category highlighting the top 20 (see Table 1). For the review quarter, three commercial banks and one building society were found to be central to the network as they were ranked in the top 5 for three or more categories. These institutions represent a combined total of 39.7 per cent of total system assets, and 50.1 per cent of net interbank assets and 25.9 per cent of net interbank liabilities at June 2014 (see Table 2). The results indicate that these institutions are a primary source of funding to the interbank market and as such may be considered as core institutions. As such, with the exception of one large commercial bank, these institutions are significantly exposed to counterparty risk upon default of their respective counterparties. On the other hand, the large commercial bank posed counterparty risk to other institutions in the network recording the second highest number of liabilities to counterparties (out-degrees) for the period valuing $14.74 billion (net), after foreign institutions. It was also considered to be the most dominant player in the market as it relates to the quality of its connections illustrated with the eigenvector centrality indicator as well as the ability to transmit contagion in a few steps as measured by its closeness centrality.

Table 1: Centrality measures for the top 20 institutions in the Jamaican financial institution network at June 2014

Rank - June 2014	Degree Centrality: In-Degree		Degree Centrality: Out-Degree		Closeness Centrality		Betweenness Centrality		Eigenvector Centrality	
1	FOREIGN	10	BS2	15	**CB3**	0.024	BS2	142.2	**CB2**	0.070
2	**CB2**	9	**BS1**	14	**CB2**	0.024	**BS1**	116.6	**CB3**	0.069
3	SD2	9	**CB3**	11	**CB7**	0.024	**CB2**	106.5	**CB7**	0.067
4	**CB1**	8	**CB7**	11	**CB1**	0.023	**CB7**	99.1	**BS1**	0.067
5	CB4	7	SD12	9	**BS1**	0.023	**CB3**	83.3	**CB1**	0.066
6	CB3	6	CB2	8	BS2	0.023	CB4	75.7	CB4	0.062
7	SD10	6	CB6	7	CB4	0.022	SD12	64.3	BS2	0.062
8	SD7	5	CB4	7	CB6	0.020	CB6	60.7	SD2	0.052
9	OFI	5	FIA2	7	SD2	0.020	CB1	54.2	FOREIGN	0.051
10	SD6	5	CB1	7	FOREIGN	0.020	FOREIGN	15.0	CB6	0.049
11	SD8	5	SD8	3	SD8	0.019	SD2	12.6	SD8	0.042
12	CB7	5	BS3	2	SD12	0.019	SD8	4.7	SD12	0.040
13	FIA1	4	FIA1	2	SD10	0.018	SD10	4.5	FIA2	0.034
14	CB6	3	SD1	1	SD6	0.018	SD6	3.3	SD6	0.033
15	SD1	3	SD2	1	FIA2	0.018	OFI	3.0	FIA1	0.032
16	SD9	3	SD3	1	SD7	0.018	FIA2	2.9	SD10	0.032
17	SD13	3	SD5	1	OFI	0.018	SD1	2.5	SD7	0.030
18	BS1	3	SD6	1	FIA1	0.017	BS3	1.6	OFI	0.027
19	BS3	2	SD7	0	SD9	0.016	FIA1	1.5	SD9	0.018
20	SD4	1	SD4	0	SD1	0.016	SD7	0.0	BS3	0.018

Table 2: Top 5 institutions in the Jamaican financial institution network at June 2014

	Net Credit Liabilities	Net Credit Liabilities as a % Total Net Credit Liabilities	Total Assets	Total Assets as a % of Total System Assets	Net Credit Assets	Net Credit Assets as a % Total Assets	Net Credit Assets as a % Total System Assets	Net Credit Assets as a % Total Net Credit Assets	Regulatory Capital	Net Credit Assets as a % Regulatory Capital
System	*123,251,582.2*		*1,953,599,188.0*		*123,251,582.2*				*245,265,184*	
CB1	12,824,413.54	10.41	254,443,009.00	13.02	28,491,318.51	11.20	1.46	23.12	20,004,652.00	142.42
CB2	14,743,359.64	11.96	345,455,457.00	17.68	8,530,016.49	2.47	0.44	6.92	27,087,218.00	31.49
CB3	894,298.14	0.73	16,075,658.00	0.82	4,955,797.42	30.83	0.25	4.02	1,976,929.00	250.68
CB7	3,055,821.18	2.48	79,938,995.00	4.09	11,332,611.68	14.18	0.58	9.19	10,209,222.00	111.00
BS1	362,913.50	0.29	80,001,053.00	4.10	8,389,035.30	10.49	0.43	6.81	8,412,411.00	99.72

4.0 Model of Interbank Contagion

Understanding the shock transmission throughout the interbank network can assist in the estimation of impaired capital, determine systemic and vulnerable institutions and track the path of contagion. This paper uses a similar analysis to Espoinosa-Vega and Solé (2010) in modelling network contagion for Jamaica.[10] The model assumes an initial balance sheet identity for each bank *i* as follows:

$$\sum_j x_{ji} + a_i = k_i + b_i + d_i + \sum_j x_{ij} \ldots\ldots\ldots(9)$$

where x_{ji} represents bank i loans to (funding to) bank j, a_i represents bank i's other assets, k_i represents bank i's capital, b_i represents long-term and short-term borrowing (excluding interbank loans), d_i represents deposits, and x_{ij} represents bank *i* borrowing from (funding from) bank *j*.

4.1 Credit Channel

The credit channel simulates domino effects triggered by the default of an institution's interbank obligations. Although a bank defaults, other banks are assumed to be able to roll over their funding sources and therefore don't require fire sales. The default of each individual institution in the network is simulated based on the assumption of various losses given default represented by λ. Losses based on simulated defaults are absorbed by system's capital and the sequence of

[10] The Bank Network 2.0 Microsoft-Excel add-in developed by the same authors was used to carry out the simulations.

subsequent defaults triggered by the event is tracked. The simulation assumes initially that institution h fails at t=0 and therefore λ of its debts to the rest of institutions will not be repaid. Next, for each of the other institutions, if the amount of losses suffered by that institution is larger than the amount of capital of that particular institution, then that institution becomes insolvent. This process continues until all institutions have been assessed and no further failures are triggered. The balance sheet identity for bank i after the default of institution h becomes:

$$\sum_{j\neq h} x_{ij} + (1-\lambda)x_{hi} + a_i = (k_i - \lambda x_{hi}) + b_i + d_i + \sum_j x_{ij} \ldots\ldots\ldots(10)$$

Therefore, the default condition is as follows:

If $\sum_h \lambda x_{hi} > k_i$, then i also defaults.

4.2 Credit-plus-Funding Channel

The credit-plus-funding channel simulates the effects that default of an institution also leads to a liquidity tightening for institutions funded by the defaulting institution. A bank's ability to replace unforeseen withdrawal of interbank funding depends on liquidity conditions in the money market. Tightening liquidity and the absence of alternative funding sources may result in forced sales (fire sales) of assets by financial institutions to restore their balance sheet identity. This tightening could occur due the perception by lenders that an institution has a business model or portfolio similar to a seemingly weak institution. The simulation assumes that institutions are no longer able to replace all the funding granted by the defaulted institutions which could result in a fire sale of assets. If bank i is able to replace only a fraction $(1-\rho)$ of the lost funding from bank h, it may be forced to sell its assets at a discount, δ, which would be worth $(1+\delta)\rho x_{ih}$ in book value terms. The total funding shortfall induced loss, $\delta\rho x_{ih}$, is absorbed by capital which transforms the balance sheet identity as follows:

$$\sum_j x_{ij} - (1+\delta)\rho x_{ih} + a_i = (k_i - \delta\rho x_{ih}) + b_i + d_i + \sum_j x_{ij} - \rho x_{ih} \ldots\ldots\ldots(11)$$

At each stage of the simulation, an institution's capital is decreased by the asset fire sale which leads to the following default condition:

If $\sum_h \lambda x_{hi} + \sum_h \delta\rho x_{ih} > k_i$, then i also defaults.

5.0 Simulation Results

The model developed by Espoinosa-Vega and Solé (2010) provides a measure of the domino effect of capital losses and failures induced by alternative credit events, provides insight on the additional systemic institutions. It also allows for the quantification of potential capital losses at the institutional level, allows for the identification of vulnerabilities as well as the ability to track potential contagion paths. Simulations were carried out to determine the contagion pass through effects in the quarters before, during and after the National Debt Exchange (NDX) exercise carried out between the Government of Jamaica (GOJ) and its bondholders. The NDX transaction was completed on 22 February 2013 and as such the simulations were carried out for the December 2012, March 2013 and June 2013 quarters. In addition, the data utilized reflected gross bilateral exposures for DTIs and SDs as most of the transactions are concentrated among these institutions.[11,12] Finally, the simulations were two-fold, focusing on domestic funding relationships between institutions, then extending the simulation to include foreign institutions. Based on network topology results, institutions were found to be significantly exposed to foreign institutions.

5.1 Domestic Institutions: DTIs and SDs

5.1.1 Credit Shock Results

Similar to Hausenblas, *et al* (2012), λ is assumed to be 100 per cent as the model utilizes unsecured or uncollaterlised transactions. Additionally, the resolution period after default may influence the time value of the interbank claims. Furthermore, bankruptcy costs could also reduce the remaining value of the claim for creditors. The results based on the pure credit shock did not indicate significant differences in the results before or after the NDX. One large commercial bank was found to be the main systemic player for each of the three quarters under review inducing the failure of another smaller commercial bank. A hypothetical default of this large commercial bank on its interbank claims would have led to losses of approximately 15.3

[11] The exclusion of other sectors to the assessment did not significantly alter the simulations.
[12] The institutions which form part of the top 11 SDs may vary for the quarters under review. For this analysis, all institutions which fell within the top 11 during any of the review quarters were considered part of the sector.

per cent, 17.4 per cent and 16.8 per cent of the combined capital of the financial system under review for December 2012, March 2013 and June 2013, respectively (see Table 3). Additionally, although not considered significant enough to cause contagion, another large commercial bank also posed risk to other institutions with the second highest level of the index of contagion for all three quarters. The simulations also identified vulnerable institutions which were weakened by the shocks but not to a level of default. Specifically, three securities dealers were found to be vulnerable due mainly to credit exposures to commercial banks.

Table 3: Results for Simulation 1a (Credit Channel)

	# of Induced Failures			Failed Capital (in % of total capital)			Contagion Rounds			Index of Contagion			*Index of Vulnerability-Author's Calculations*		
	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	*Dec-12*	*Mar-13*	*Jun-13*
CB1	0	0	0	**12.1**	**12.1**	**11.9**	0	0	0	1.9	2.3	2.3	*0.9*	*1.9*	*0.2*
CB2	0	**1**	0	**15.3**	**17.4**	**16.8**	0	**1**	0	3.3	**11.1**	**11.8**	*0.1*	*0.2*	*0.1*
CB3	0	0	0	1.3	1.4	1.3	0	0	0	0.3	0.7	0.3	*1.8*	***22.3***	***47.3***
CB4	0	0	0	3.0	2.9	2.7	0	0	0	0.7	0.9	1.6	*14.3*	*19.6*	*3.7*
CB5	0	0	0	2.7	3.4	3.4	0	0	0	1.0	0.8	0.5	*6.5*	*1.8*	*1.4*
CB6	0	0	0	2.9	2.9	2.7	0	0	0	0.0	0.2	0.1	*1.0*	*0.4*	*0.2*
CB7	0	0	0	2.1	2.2	2.1	0	0	0	0.3	0.5	0.8	*1.2*	*4.9*	*2.9*
BS1	0	0	0	4.2	4.6	4.4	0	0	0	0.0	0.0	0.0	*2.6*	*2.8*	*8.1*
BS2	0	0	0	7.9	8.0	8.9	0	0	0	0.0	0.0	0.0	*0.5*	*1.1*	*0.6*
BS3	0	0	0	1.8	1.8	2.1	0	0	0	0.0	0.0	0.0	*5.3*	*8.3*	*7.0*
BS4	0	0	0	0.9	1.0	1.0	0	0	0	1.4	1.2	0.4	*13.0*	*9.6*	*4.4*
SD1	0	0	0	7.6	7.6	7.6	0	0	0	0.0	0.0	0.0	*8.1*	*5.8*	*23.5*
SD2	0	0	0	10.3	9.9	9.8	0	0	0	0.0	0.0	0.0	*4.4*	*3.9*	*8.5*
SD3	0	0	0	0.0	0.6	0.6	0	0	0	0.0	0.0	0.0	-	***24.6***	***21.3***
SD4	0	0	0	2.2	2.1	2.0	0	0	0	0.3	0.3	0.3	*0.1*	*0.8*	*1.5*
SD5	0	0	0	0.9	0.5	0.5	0	0	0	0.5	0.2	0.2	***62.5***	***32.6***	***31.7***
SD6	0	0	0	10.3	8.6	8.2	0	0	0	0.0	0.0	0.0	*2.0*	***22.7***	***46.5***
SD7	0	0	0	1.1	0.9	0.9	0	0	0	0.0	0.0	0.0	*4.0*	*1.9*	*3.3*
SD8	0	0	0	6.0	6.0	5.9	0	0	0	0.1	0.0	0.1	*2.1*	*1.8*	*1.7*
SD9	0	0	0	0.6	0.6	0.6	0	0	0	0.0	0.0	0.0	*3.8*	*6.1*	*6.9*
SD10	0	0	0	1.5	1.4	1.3	0	0	0	0.0	0.0	0.0	*2.0*	*1.6*	*1.8*
SD11	0	0	0	1.5	1.5	1.4	0	0	0	0.0	0.0	0.0	*2.2*	*1.0*	*0.4*
SD12	0	0	0	0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	-	-	-
SD13	0	0	0	1.6	1.5	1.5	0	0	0	0.0	0.0	0.0	*0.8*	*0.9*	*0.6*
FIA1	0	0	0	2.2	2.3	2.4	0	0	0	0.8	0.8	3.9	*4.0*	*6.2*	*2.1*
FIA2	0	0	0	0.1	0.1	0.1	0	0	0	0.0	0.0	0.0	*5.1*	*4.7*	*2.2*

Notes: Failed Capital is the average amount of capital lost per bank due to the failure of this bank. Index of contagion measures the percentage capital loss of other banks due to the failure of this bank. Index of vulnerability measures the average percentage capital loss due the default of all other banks. This measure was adjusted to include only percentage losses which were greater than 0.0 per cent.

5.1.2 Credit-plus-Funding Shock Results[13]

The addition of the funding shocks introduced the initial assumption of an 83.6 per cent roll-over ratio of interbank debt, ρ, as well as a 25.0 per cent haircut, δ, in the fire sale of assets.[14] The roll-

[13] It is not possible to assess funding risk when foreign institutions are included in the simulation. This is due to the fact that capital data is not available for foreign institutions. As such, only credit shocks are simulated.

over ratio of 83.6 per cent was determined by one less the reduction of domestic interbank liabilities between September 2008 and December 2008 reflecting the period for which Jamaica began to experience the second round effects from the global financial crisis. The 25.0 per cent haircut was determined based on BOJ's collateral policy where banks who borrow from BOJ as the lender of last resort would receive 75.0 per cent of the value of the collateral. However, the relatively conservative assumptions did not reveal significant results and as such other worse case scenarios were utilized. Under the assumption that banks are unable to roll any of their funding and face a haircut of 50.0 per cent on assets indicated that the vulnerability of domestic institutions on average would increase as measured by the index of vulnerability. No additional contagion effects were identified. However, one building society and two securities dealers were identified as the most vulnerable institutions within the network for the periods under review (see Table 4).

Table 4: Results for Simulation 2a (Credit-plus-Funding Channel)

	# of Induced Failures			Failed Capital (in % of total capital)			Contagion Rounds			Index of Contagion			*Index of Vulnerability-Author's Calculations*		
	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	*Dec-12*	*Mar-13*	*Jun-13*
CB1	0	0	0	**12.1**	**12.1**	**11.9**	0	0	0	2.0	3.3	2.3	*0.7*	*1.3*	*0.8*
CB2	0	**1**	0	**15.3**	**17.4**	**16.8**	0	**1**	0	3.3	**11.4**	**11.9**	*0.7*	*1.9*	*2.3*
CB3	0	0	0	1.3	1.4	1.3	0	0	0	0.3	1.6	0.9	*1.2*	*9.9*	*8.7*
CB4	0	0	0	3.0	2.9	2.7	0	0	0	1.6	1.8	1.9	*6.2*	*6.0*	*3.9*
CB5	0	0	0	2.7	3.4	3.4	0	0	0	1.2	1.0	0.6	*4.1*	*2.2*	*1.4*
CB6	0	0	0	2.9	2.9	2.7	0	0	0	0.1	0.2	0.1	*0.5*	*0.7*	*0.3*
CB7	0	0	0	2.1	2.2	2.1	0	0	0	0.3	0.8	0.9	*1.6*	*5.2*	*5.5*
BS1	0	0	0	4.2	4.6	4.4	0	0	0	0.4	0.3	0.9	*2.6*	*2.8*	*6.7*
BS2	0	0	0	7.9	8.0	8.9	0	0	0	0.2	0.2	0.2	*0.5*	*1.0*	*0.5*
BS3	0	0	0	1.8	1.8	2.1	0	0	0	0.1	0.1	0.1	*5.3*	*8.3*	*7.0*
BS4	0	0	0	0.9	1.0	1.0	0	0	0	1.5	1.3	0.5	***90.9***	***69.8***	*13.3*
SD1	0	0	0	7.6	7.6	7.6	0	0	0	0.7	0.9	1.0	*8.1*	*5.8*	*23.5*
SD2	0	0	0	10.3	9.9	9.8	0	0	0	1.3	1.2	2.3	*3.7*	*3.9*	*8.5*
SD3	0	0	0	0.0	0.6	0.6	0	0	0	0.0	0.1	0.1	*0.0*	*24.6*	*21.3*
SD4	0	0	0	2.2	2.1	2.0	0	0	0	0.3	0.4	0.4	*1.5*	*2.6*	*3.1*
SD5	0	0	0	0.9	0.5	0.5	0	0	0	0.8	0.3	0.3	***89.5***	*5.4*	***49.5***
SD6	0	0	0	10.3	8.6	8.2	0	0	0	0.2	2.1	4.1	*1.4*	***22.7***	***46.5***
SD7	0	0	0	1.1	0.9	0.9	0	0	0	0.1	0.0	0.1	*4.0*	*1.9*	*3.4*
SD8	0	0	0	6.0	6.0	5.9	0	0	0	0.3	0.2	0.3	*1.8*	*1.8*	*1.4*
SD9	0	0	0	0.6	0.6	0.6	0	0	0	0.0	0.1	0.1	*3.8*	*6.1*	*6.9*
SD10	0	0	0	1.5	1.4	1.3	0	0	0	0.1	0.1	0.1	*2.0*	*1.7*	*1.8*
SD11	0	0	0	1.5	1.5	1.4	0	0	0	0.0	0.0	0.0	*2.2*	*1.0*	*0.4*
SD12	0	0	0	0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	*0.0*	*0.0*	*0.0*
SD13	0	0	0	1.6	1.5	1.5	0	0	0	0.0	0.0	0.0	*0.8*	*0.9*	*0.6*
FIA1	0	0	0	2.2	2.3	2.4	0	0	0	0.9	1.0	3.9	*6.4*	*6.5*	*13.9*
FIA2	0	0	0	0.1	0.1	0.1	0	0	0	0.0	0.0	0.0	*5.1*	*4.7*	*3.0*

Notes: Failed Capital is the average amount of capital lost per bank due to the failure of this bank. Index of contagion measures the percentage capital loss of other banks due to the failure of this bank. Index of vulnerability measures the average percentage capital loss due the default of all other banks. This measure was adjusted to include only percentage losses which were greater than 0.0 per cent.

[14] The haircut assumed in this framework does not facilitate a disaggregation of assets upon which the haircut is applied. Instead, it assumes a one off haircut regardless of the class of assets on the balance sheet.

5.2 Domestic and Foreign Institutions

5.2.1 Credit Shock Results

The interbank market includes a large number of transactions between domestic and foreign institutions. This is mainly due to the fact that the main banks in Jamaica have foreign parents. Interbank funding to foreign institutions tend to be in the form of deposits held with overseas institutions. As a result it was important to analyse the contagion implications if shocks to overseas institutions impact on domestic institutions given that exposures typically exceed 100.0 per cent of capital.

In addition to the large commercial bank, foreign institutions also induce failures within the interbank market. In particular, foreign institutions induce four failures in one round of contagion prior to the NDX compared to six failures in two rounds of contagion during the NDX quarter as well as during the June 2013 quarter. The results indicate that a hypothetical default of foreign institutions would have led to losses of approximately 20.3 per cent, 32.3 per cent and 40.4 per cent of the combined capital of the financial system under review for December 2012, March 2013 and June 2013, respectively (see Table 5). This was also evidenced by percentage capital losses of other banks due to their default of 46.9 per cent, 46.6 per cent and 62.6 per cent for December 2012, March 2013 and June 2013, respectively. Collectively, foreign institutions posed the greatest contagion risk to four commercial banks and two building societies for the periods under review.

Table 5: Results for Simulation 1b (Credit Channel)

	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13	Dec-12	Mar-13	Jun-13
	# of Induced Failures			Failed Capital (in % of total capital)			Contagion Rounds			Index of Contagion			Index of Vulnerability- OWN CALC.		
CB1	0	0	0	12.1	12.1	11.9	0	0	0	1.9	2.3	2.3	**33.9**	**23.3**	**33.4**
CB2	0	**1**	0	**15.3**	**17.4**	**16.8**	0	**1**	0	3.3	**11.1**	**11.8**	**21.8**	**21.5**	16.8
CB3	0	0	0	1.3	1.4	1.3	0	0	0	0.3	0.7	0.3	**21.4**	**33.4**	**64.9**
CB4	0	0	0	3.0	2.9	2.7	0	0	0	0.7	0.9	1.6	**31.4**	**39.6**	17.5
CB5	0	0	0	2.7	3.4	3.4	0	0	0	1.0	0.8	0.5	29.9	21.3	21.1
CB6	0	0	0	2.9	2.9	2.7	0	0	0	0.0	0.2	0.1	4.1	5.3	6.6
CB7	0	0	0	2.1	2.2	2.1	0	0	0	0.3	0.5	0.8	6.2	10.1	16.0
BS1	0	0	0	4.2	4.6	4.4	0	0	0	0.0	0.0	0.0	19.3	19.0	**23.4**
BS2	0	0	0	7.9	8.0	8.9	0	0	0	0.0	0.0	0.0	9.1	15.1	16.2
BS3	0	0	0	1.8	1.8	2.1	0	0	0	0.0	0.0	0.0	7.6	9.6	7.7
BS4	0	0	0	0.9	1.0	1.0	0	0	0	1.4	1.2	0.4	13.0	9.6	4.4
SD1	0	0	0	7.6	7.6	7.6	0	0	0	0.0	0.0	0.0	10.8	10.6	23.5
SD2	0	0	0	10.3	9.9	9.8	0	0	0	0.0	0.0	0.0	4.0	4.1	9.5
SD3	0	0	0	0.0	0.6	0.6	0	0	0	0.0	0.0	0.0	-	24.6	15.7
SD4	0	0	0	2.2	2.1	2.0	0	0	0	0.3	0.3	0.3	0.1	0.5	0.9
SD5	0	0	0	0.9	0.5	0.5	0	0	0	0.5	0.2	0.2	**62.5**	**32.6**	**31.7**
SD6	0	0	0	10.3	8.6	8.2	0	0	0	0.0	0.0	0.0	1.4	15.0	**62.0**
SD7	0	0	0	1.1	0.9	0.9	0	0	0	0.0	0.0	0.0	3.2	3.0	5.3
SD8	0	0	0	6.0	6.0	5.9	0	0	0	0.1	0.0	0.1	2.2	1.7	1.5
SD9	0	0	0	0.6	0.6	0.6	0	0	0	0.0	0.0	0.0	4.9	6.9	6.7
SD10	0	0	0	1.5	1.4	1.3	0	0	0	0.0	0.0	0.0	2.1	1.7	2.9
SD11	0	0	0	1.5	1.5	1.4	0	0	0	0.0	0.0	0.0	1.8	0.8	0.5
SD12	0	0	0	0.0	0.0	0.0	0	0	0	0.0	0.0	0.0	-	-	-
SD13	0	0	0	1.6	1.5	1.5	0	0	0	0.0	0.0	0.0	0.8	0.5	0.9
FIA1	0	0	0	2.2	2.3	2.4	0	0	0	0.8	0.8	3.9	3.4	5.2	3.1
FIA2	0	0	0	0.1	0.1	0.1	0	0	0	0.0	0.0	0.0	5.5	6.3	4.5
FOREIGN	**4**	**6**	**6**	**20.3**	**32.3**	**40.4**	**1**	**2**	**2**	**46.9**	**46.6**	**62.6**	-	-	-

Notes: Failed Capital is the average amount of capital lost per bank due to the failure of this bank. Index of contagion measures the percentage capital loss of other banks due to the failure of this bank. Index of vulnerability measures the average percentage capital loss due the default of all other banks. This measure was adjusted to include only percentage losses which were greater than 0.0 per cent.

6.0 Conclusion and Policy Implications

This paper examined contagion in the Jamaican financial system through the financial institution network exposures. First, network topology was used to determine the structure of the Jamaican financial institution network, identify significant institutions within the network and track the evolution of the network over time. Secondly, the resilience of the network was assessed by simulating credit and funding shock to the Jamaican financial system, similar to Espinosa-Vega and Solé (2010). This assessment can assist the BOJ in understanding the significance of institutions to systemic risk within the network. Notably, the more interconnected the financial network becomes, the greater the likelihood of shock amplifications

The financial institution network in Jamaica was revealed to utilize less than 20.0 per cent of possible links over the period March 2012 to June 2014. These funding relationships were concentrated in a small number of institutions which had a large number of counterparties. The results also indicate that there are five institutions which should be closely monitored for having characteristics of systemic importance to the network at end-June 2014, based on centrality measures. The on-going assessment of network topology can be used in conjunction with other methodologies such as the Basel III SIFI scoring framework and conditional value-at-risk (CoVaR) to identify SIFIs. For instance, the Basel III scoring framework indicates that for Jamaica, the two major commercial banks are SIFIs.[15]

It is important to note that although the size of an institution's network assets and liabilities signals their importance within a network, assessing institutions that are central to the network allows for understanding shock amplifications. On-going analysis of the value of transactions as well as the topology of the financial institution network will allow the BOJ to identify trends in lending patterns throughout the network and tailor regulations towards reducing contagion risk. Additionally, the identification of firm and group interconnectedness at the institution and group level becomes a crucial element in the construction of institutional recovery plans.

Conducting simulations for DTIs, SDs, and foreign institutions within the network indicated that domestic institutions were significantly exposed to foreign institutions resulting in failures upon hypothetical defaults of foreign institutions. Although these results indicate the relevance of foreign institutions on domestic institutions, the likelihood of foreign institutions defaulting is a condition beyond the control of assessment for local authorities. In addition, foreign institutions are aggregated for the purpose of analysis and include institutions that are dispersed both geographically and economically across the US, UK, Canada and the Caribbean reflecting a low probability of co-default.

An assessment of the simulations excluding foreign institutions revealed only one default between two commercial banks. This could be due to the fact that institutions' uncollateralised exposures are typically less than roughly 30.0 per cent of capital. Notwithstanding, such simulations can be utilized by the BOJ to conduct stressed simulations and track the path of contagion. It also provides a great deal of flexibility in setting the assumptions for the loss given

[15] See Lewis, Senior and Smith Yee (2014).

default, roll over ratio and haircut. In addition, the results assumed a pure contagion shock which looks only on the failure of a particular institution for idiosyncratic reasons. However, by assessing macro-contagion scenarios wherein all institutions within the system are weakened by similar macroeconomic shocks, the BOJ would be in a position to assess the second round effect of the macro-shock when compounded by the interbank lending relationship.

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Appendix

Appendix A

Figure A1: In-degree distribution of the network

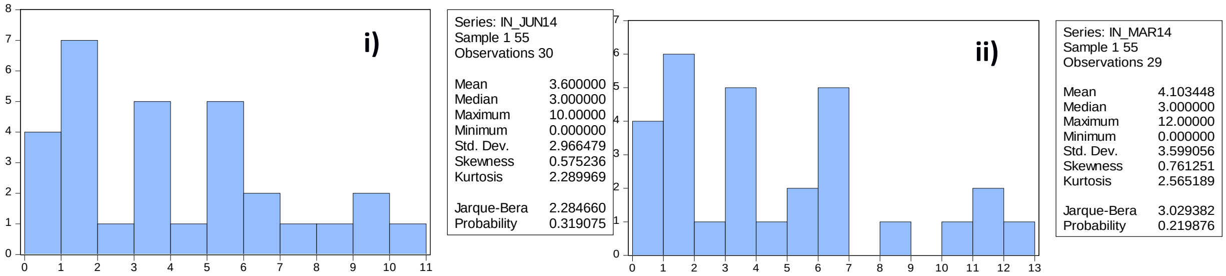


Figure A2: Out-degree distribution of the network

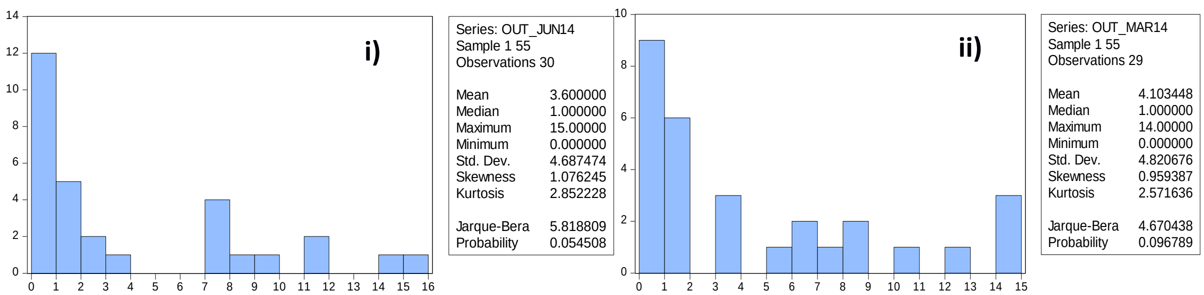


Figure A3: Betweenness centrality distribution

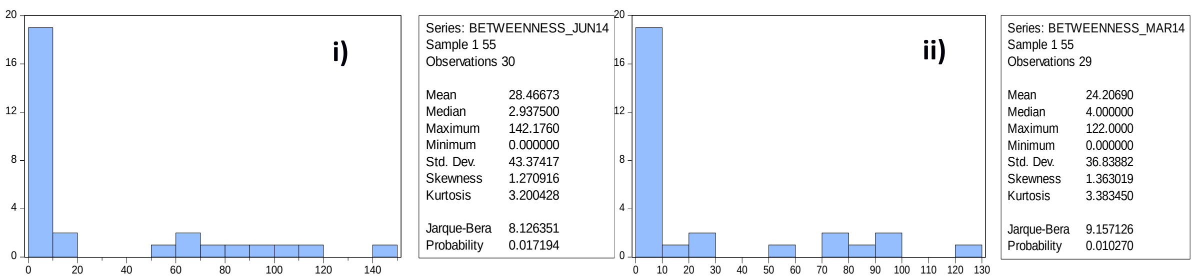
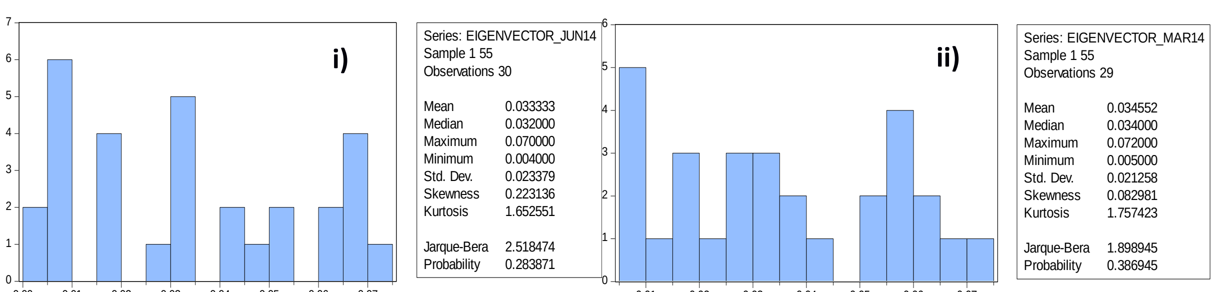


Figure A4: Eigenvector centrality distribution



Appendix B

B.1 Domestic Credit Simulation

Figure B.1.1 Capital Losses as per cent of pre-shock capital December 2012

	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2
Trigger Institution:	(Capital Impairment in Percent of Pre-shock Capital)																									
CB1	--	0.01		0.14		0.08	0.53		0.35	9.56		16.12	0.07						1.95			1.09			2.10	0.63
CB2		--	0.01	0.16	0.37	0.29	2.77	7.35	3.04				13.96		0.02		3.92				4.84	3.32		2.13	5.99	
CB3			--				0.02	1.03	0.86			0.01	0.22		0.02		0.13	0.36	0.31	7.38	2.86					
CB4	1.38	0.22	0.01	--	1.46	0.24	1.48	3.20			12.99							11.32			0.03					8.61
CB5	0.39				--			3.87	0.13				1.48			62.49		0.47		0.90						
CB6						--		0.22	0.02						0.34						0.10			0.24		
CB7			0.08				--			1.12									4.09	3.14						
BS1								--																		6.11
BS2		0.07							--															0.16		
BS3										--																
BS4				46.58							--															
SD1												--														
SD2									0.27				--													
SD3														--												
SD4				10.34					0.01						--											
SD5					17.75											--										
SD6									0.12								--									
SD7																		--								
SD8						3.21			0.01										--							
SD9																				--						
SD10																					--					
SD11																						--				
SD12																							--			
SD13																								--		
FIA1			7.13										6.48												--	
FIA2																										--

Figure B.1.2 Capital Losses as per cent of pre-shock capital March 2013

	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2
Trigger Institution:	(Capital Impairment in Percent of Pre-shock Capital)																									
CB1	--	0.13	0.83		0.47	0.69	6.66		0.15	8.33		21.84	0.96						0.55		0.11	1.17			3.13	1.97
CB2	1.85	--	**100.00**	4.75	0.38		16.93	6.67	3.88			0.57	12.88		0.29		44.86	0.27	0.43	7.60	4.39	0.14		1.86	9.29	
CB3	2.98	0.21	--				0.39	0.34	1.38			0.49	0.26		0.22		0.49	0.26	0.43	7.60	2.89					
CB4	0.94	0.32	15.65	--	0.60	0.12	0.33	2.64			9.59			24.55				6.92			0.35					7.47
CB5	1.69	0.31			--			4.25	0.21				2.00			32.59		0.22		2.43						
CB6			8.46			--		0.24	0.73			0.19	0.40		1.95				0.56		0.16			0.18		
CB7							--		0.20										7.17	6.88						
BS1								--																		
BS2									--															0.72		
BS3										--																
BS4				42.52							--															
SD1												--														
SD2													--													
SD3														--												
SD4				11.60											--											
SD5					5.56											--										
SD6																	--									
SD7																		--								
SD8							0.12												--							
SD9																				--						
SD10			1.14																		--					
SD11																						--				
SD12																							--			
SD13																								--		
FIA1			7.46										7.00									1.75			--	
FIA2																										--

Figure B.1.3 Capital Losses as per cent of pre-shock capital June 2013

	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2
Trigger Institution:	(Capital Impairment in Percent of Pre-shock Capital)																									
CB1	--	0.02					0.20		0.11	6.95		23.45	0.09						0.06		0.16	0.56			0.81	0.58
CB2		--		0.05	0.06		13.96	9.25	1.47				12.02		0.01		93.01	0.10	0.01		4.14	0.18		1.70	5.45	
CB3			--				0.07	0.19	1.10				0.36		0.02		0.04	0.18	0.51	4.80	4.34					
CB4	0.32	0.10		--	0.36	0.15	0.14	28.58			4.42			4.41				12.47			0.03					
CB5					--			2.22	0.17				1.71			31.67		0.38		1.33					0.01	
CB6		0.02				--		0.16	0.02						4.39						0.11			0.12		
CB7		0.39	19.13		0.01		--												6.19	14.60						
BS1								--																		6.11
BS2	0.01	0.12							--															0.10		
BS3										--																
BS4				7.73							--			38.17												
SD1												--														
SD2													--													
SD3														--												
SD4				12.32											--											
SD5					5.27											--										
SD6																	--									
SD7				0.18														--								
SD8				1.94			0.04												--							
SD9																				--						
SD10																					--					
SD11																						--				
SD12																							--			
SD13																								--		
FIA1			75.47										28.46									0.46			--	0.00
FIA2				0.17																						--

B.2 Domestic Credit-plus-Funding Simulation

Figure B.2.1 Capital Losses as per cent of pre-shock capital December 2012

	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2
Trigger Institution:	(Capital Impairment in Percent of Pre-shock Capital)																									
CB1	--	0.01		2.88	0.87	0.08	0.53		0.35	9.56		16.12	0.07						1.95			1.09			2.10	0.63
CB2	0.01	--	0.01	0.70	0.38	0.29	2.77	7.35	3.11				13.96		0.02		3.92				4.84	3.32		2.13	5.99	
CB3			--				0.04	1.03	0.86			0.01	0.22		0.02		0.13	0.36	0.31	7.38	2.86				2.15	
CB4	1.40	0.23	0.01	--	1.46	0.24	1.48	3.20			90.88		0.00		7.14			11.32			0.03					8.61
CB5	0.39	0.04		0.65	--			3.87	0.13				1.48			89.49		0.47		0.90						
CB6	0.01	0.03		0.11		--		0.22	0.02						0.34				0.79		0.10			0.24		
CB7	0.05	0.19	0.10	0.52			--			1.12									4.09	3.14						
BS1		1.00	1.63	2.21	2.98	0.15		--																		6.11
BS2	0.11	0.85	2.58		0.20	0.02			--						0.02		0.05							0.16		
BS3	0.71						0.47			--																
BS4				48.53							--															
SD1	5.08		0.02									--														
SD2	0.03	4.70	0.88		2.81				0.27				--												15.26	
SD3														--												
SD4			0.02	10.34		0.13			0.01						--											
SD5					28.03											--										
SD6		1.32	0.51						0.12								--									
SD7			0.15	2.02	0.09													--								
SD8	0.48		0.71			3.21	5.75		0.01										--							
SD9			1.70		0.10		0.45													--						
SD10		0.24	1.65	0.01		0.03															--					
SD11	0.07	0.16																				--				
SD12																							--			
SD13		0.11				0.06			0.02															--		
FIA1	0.19	0.43	7.13										6.48												--	
FIA2				0.14				0.07																		--

Figure B.2.2 Capital Losses as per cent of pre-shock capital March 2013

Trigger Institution:	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2
	(Capital Impairment in Percent of Pre-shock Capital)																									
CB1	--	2.99	14.18	1.95	3.59	0.69	6.66		0.15	8.33		21.84	0.96						0.55		0.11	1.17			3.13	1.97
CB2	1.94	--	**100.00**	9.22	0.45	1.94	16.93	6.67	3.88			0.57	12.88		0.29		44.86	0.27	0.43	7.60	4.59	0.14		1.86	11.50	
CB3	3.26	4.30	--	3.62		1.94	0.39	0.34	1.38			0.49	0.26		0.22		0.49	0.26	0.43	7.60	3.44				2.28	
CB4	0.94	0.75	15.65	--	0.60	0.12	0.33	2.64			69.85			24.55	7.85			6.92			0.35					7.47
CB5	1.75	0.78		0.35	--			4.25	0.21				2.00			5.40		0.22		2.43						
CB6	0.84		8.46	0.61		--		0.24	0.73			0.19	0.40		1.95				0.56		0.16			0.18		
CB7	0.60	1.15	0.31	0.12			--		0.20										7.19	6.88						
BS1		0.96	0.57	2.73	2.90	0.19		--																		
BS2	0.51	0.62	4.81		0.26	0.99	0.37		--															0.72		
BS3	0.62									--																
BS4				43.72							--															
SD1	6.66	0.42	0.14			0.24						--														
SD2	0.38	3.92	0.94		2.95	0.67							--												15.18	
SD3				2.57										--												
SD4		0.46	0.17	11.60		0.79									--											
SD5					8.11											--										
SD6		12.18	0.16														--									
SD7		0.47	0.89	1.11	0.31													--								
SD8	0.14	0.33	0.89			0.57	9.96												--							
SD9			1.82		0.23		1.84													--						
SD10	0.65	0.54	2.62	0.83		0.25															--					
SD11	0.78	0.66																				--			0.56	
SD12																							--			
SD13		0.89				0.46			0.69															--		
FIA1	0.29	0.66	7.46										7.00									1.75			--	
FIA2	0.82			0.13																						--

Figure B.2.3 Capital Losses as per cent of pre-shock capital June 2013

Trigger Institution:	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2
	(Capital Impairment in Percent of Pre-shock Capital)																									
CB1	--	0.02		0.71			0.20		0.12	6.95		23.45	0.09						0.06		0.16	0.56			0.81	0.58
CB2	0.01	--		0.35	0.07	0.06	15.54	9.25	1.58				12.02		0.01		93.01	0.10	0.01		4.14	0.18		1.70	5.47	
CB3			--				6.04	0.19	1.10				0.36		0.02		0.04	0.18	0.51	4.80	4.34				20.16	
CB4	0.32	0.10		--	0.36	0.15	0.14	28.58			15.06			4.41	8.12			12.76	0.45		0.03					2.41
CB5		0.01		0.23	--			2.22	0.17				1.71			49.51		0.38		1.33					0.01	
CB6		0.02		0.08		--		0.16	0.02						4.39						0.11			0.12		
CB7	0.02	1.26	19.18	0.05	0.01		--												6.19	14.60						
BS1		1.21	0.32	23.39	1.43	0.13		--																		6.11
BS2	0.05	0.51	3.77		0.22	0.03			--															0.10		
BS3	0.62									--																
BS4				8.53							--			38.17												
SD1	7.50		0.01									--														
SD2	0.04	3.49	1.33		2.45								--												57.01	
SD3				0.49							11.61			--												
SD4			0.02	12.32		1.65									--											
SD5					7.61	0.00										--										
SD6		22.68	0.12														--									
SD7			0.06	2.15	0.05													--								
SD8	0.01		1.14	1.94			8.77												--							
SD9			1.13		0.12		2.15													--						
SD10	0.01	0.17	2.23	0.01		0.03															--					
SD11	0.03	0.01																				--			0.13	
SD12																							--			
SD13		0.08				0.03			0.01															--		
FIA1	0.08	0.40	75.47										28.46									0.46			--	
FIA2				0.17				0.07																		--

B.3 Domestic + Foreign Credit Simulation

Figure B.3.1 Capital Losses as per cent of pre-shock capital December 2012

(Capital Impairment in Percent of Pre-shock Capital)

Trigger Institution:	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2	FOREIGN
CB1	--	0.01		0.14		0.08	0.53		0.35	9.56		16.12	0.07						1.95			1.09			2.10	0.63	
CB2		--	0.01	0.16	0.37	0.29	2.77	7.35	3.04				13.96		0.02		3.92				4.84	3.32		2.13	5.99		
CB3			--				0.02	1.03	0.86			0.01	0.22		0.02		0.13	0.36	0.31	7.38	2.86						
CB4	1.38	0.22	0.01	--	1.46	0.24	1.48	3.20			12.99							11.32			0.03					8.61	
CB5	0.39				--			3.87	0.13				1.48			62.49		0.47		0.90							
CB6						--		0.22	0.02						0.34						0.10			0.24			
CB7			0.08				--			1.12									4.09	3.14							
BS1								--																		6.11	
BS2		0.07							--															0.16			
BS3										--																	
BS4				46.58							--																
SD1												--															
SD2									0.27				--														
SD3														--													
SD4				10.34					0.01						--												
SD5					17.75											--											
SD6									0.12								--										
SD7																		--									
SD8						3.21			0.01										--								
SD9																				--							
SD10																					--						
SD11																						--					
SD12																							--				
SD13																								--			
FIA1			7.13										6.48												--		
FIA2																										--	
FOREIGN	**100.00**	**86.78**	**100.00**	**99.69**	**100.00**	16.72	25.99	**100.00**	**86.47**	11.98		16.13	1.77		0.02		0.13	0.82	2.27	8.29	2.86	1.09			2.10	6.74	--

Figure B.3.2 Capital Losses as per cent of pre-shock capital March 2013

(Capital Impairment in Percent of Pre-shock Capital)

Trigger Institution:	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2	FOREIGN
CB1	--	0.01	0.83		0.47	0.01	6.66		0.15	8.32		21.08	0.09						0.06		0.11	1.17			3.13	1.97	
CB2	10.85	--	**100.00**	4.70	0.04		16.93	6.67	3.88			0.05	12.88		0.03		44.86	0.27	0.42	7.60	4.04	0.14		1.86	9.29		
CB3	2.98		--				0.04	0.34	1.38			0.05	0.26		0.02		0.05	0.26	0.40	7.60	2.89						
CB4	0.94	0.32	15.60	--	0.60	0.12	0.33	2.64			9.59			24.55				6.92			0.03					7.47	
CB5	1.69				--			4.25	0.21				2.00			32.59		0.22		2.43							
CB6			8.46			--		0.24	0.01						1.95						0.11			0.18			
CB7							--		0.02										7.17	6.81							
BS1								--																			
BS2									--															0.07			
BS3										--																	
BS4				42.05							--																
SD1												--															
SD2													--														
SD3														--													
SD4				11.51											--												
SD5					5.56											--											
SD6																	--										
SD7																		--									
SD8							0.12												--								
SD9																				--							
SD10			1.14																		--						
SD11																						--					
SD12																							--				
SD13																								--			
FIA1			7.46										6.99									1.75			--		
FIA2																						0.00				--	
FOREIGN	**100.00**	**64.17**	**100.00**	**100.00**	**100.00**	15.75	36.53	**100.00**	**100.00**	10.84	9.59	21.13	2.34	24.55	0.02	32.59	0.05	7.40	0.46	10.03	3.03	1.17		0.07	3.13	9.44	--

Figure B.3.3 Capital Losses as per cent of pre-shock capital June 2013

Trigger Institution:	CB1	CB2	CB3	CB4	CB5	CB6	CB7	BS1	BS2	BS3	BS4	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	SD13	FIA1	FIA2	FOREIGN
	(Capital Impairment in Percent of Pre-shock Capital)																										
CB1	--	0.02					0.20		0.11	6.95		23.45	0.09						0.06		0.16	0.56			0.81	0.58	
CB2		--		0.05	0.06		13.96	9.25	1.47				12.02		0.01		93.01	0.10	0.01		4.14	0.18		1.70	5.45		
CB3			--				0.07	0.19	1.10				0.36		0.02		0.04	0.18	0.51	4.80	4.34						
CB4	0.32	0.10		--	0.36	0.15	0.14	28.58			4.42			4.41				12.47			0.03						
CB5					--			2.22	0.17				1.71		0.00	31.67		0.38		1.33					0.01		
CB6		0.02				--		0.16	0.02						4.39						0.11			0.12			
CB7		0.39	19.13		0.01		--												6.19	14.60							
BS1								--																		6.11	
BS2	0.01	0.12							--															0.10			
BS3										--																	
BS4				7.73							--			38.17													
SD1												--															
SD2													--														
SD3														--													
SD4				12.32											--												
SD5					5.27											--											
SD6																	--										
SD7				0.18														--									
SD8				1.94			0.04												--								
SD9																				--							
SD10																					--						
SD11																						--					
SD12																							--				
SD13																								--			
FIA1			75.47										28.46									0.46			--		
FIA2				0.17																						--	
FOREIGN	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	13.01	81.80	**100.00**	94.59	8.53	4.42	23.46	14.18	4.41	0.03	31.67	93.05	13.14	0.57	6.13	8.68	0.73		1.70	6.27	6.70	--