WP/10/107

IMF Working Paper

Balance Sheet Network Analysis of Too-Connected-to-Fail Risk in Global and Domestic Banking Systems

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INTERNATIONAL MONETARY FUND

 WP/10/107

IMF Working Paper

Western Hemisphere Department

Balance Sheet Network Analysis of Too-Connected-to-Fail Risk in Global and Domestic Banking Systems

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April 2010

Abstract

The 2008/9 financial crisis highlighted the importance of evaluating vulnerabilities owing to interconnectedness, or Too-Connected-to-Fail risk, among financial institutions for country monitoring, financial surveillance, investment analysis and risk management purposes. This paper illustrates the use of balance sheet-based network analysis to evaluate interconnectedness risk, under extreme adverse scenarios, in banking systems in mature and emerging market countries, and between individual banks in Chile, an advanced emerging market economy.

JEL Classification Numbers: G01, G18, G28, G32

Keywords: Too-connected-to-fail, interconnectedness, banking system, network analysis

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I. TOO-CONNECTED-TO-FAIL RISK

The recent financial crisis experienced in 2008/9 has raised concerns on the adverse consequences associated with externalities inherent in the financial system. One particular concern associated with the increased pace of globalization and financial integration is interconnectedness risk, or the Too-Connected-to-Fail (TCTF) problem. The TCTF problem, in turn, brings up issues on how best to regulate TCTF institutions and how to ensure they fall within the perimeter of regulation.

A rather simplistic characterization of the TCTF problem is that the failure of one institution could lead to successive rounds of failures of other institutions in the system. The failure cascade is prompted by inter-institution exposure from the existence of direct and indirect linkages between the institutions in the system. The direct linkages arise, for instance, from balance sheet claims that expose one institution to the default of other institutions, or from the reliance on credit lines that can be withdrawn abruptly without enough advance notice. The source of indirect linkages could be through derivatives contracts and securities with market values linked to the failure of an otherwise unrelated institution.[2]

Prudential regulation and systemic risk surveillance, therefore, call for the development of methods useful for assessing TCTF risk as emphasized recently by the Bank for International Settlements (BIS), the Financial Stability Board (FSB), and the International Monetary Fund (IMF) (2009a, b). One such method, balance sheet-based network analysis, offers a practical way to analyze risks arising from linkages associated to direct exposures related to the balance sheet of financial institutions. The method is suitable for the type of data typically available to financial supervisors in most jurisdictions, and the type of cross-country banking data available from institutions such as the BIS. When secondary market prices are available, network analysis complements assessments based on market-based methods.

This paper first illustrates the use of balance sheet-based network analysis to evaluate interconnected risk from direct exposures across banking systems in advanced and emerging market country economies. The analysis, based on BIS cross-country bank claim data for reporting jurisdictions, suggests that the main sources of risk in the global banking system are shocks that could impair the solvency of banks based in the United States and the United Kingdom. Among BIS reporting jurisdictions in Latin America, it appears that the banking system in Brazil is the most resilient to global shocks while the banking system in Chile may be more exposed to funding risk from Spanish banks.

The paper then turns to the analysis of bank exposures within a jurisdiction, specifically Chile, and takes advantage of bank-specific disaggregated data on claims vis-à-vis domestic banks, foreign banks, and other non-bank financial institutions publicly reported by the supervisory agency. The country-specific analysis highlights that the main sources of domestic risk in the Chilean banking system are shocks that affect banks' claims on households and domestic corporations publicly reported by the supervisory agency. To a

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[2] Chan-Lau (2009a) and references therein.

lesser extent, the banking system is exposed to shocks affecting banks domiciled in Spain and the United States. On the basis of balance sheet data, no bank operating in Chile appears to be a TCTF institution. The results suggest that, from a financial stability perspective, the focus is better placed on linkages with foreign banks and the creditworthiness of claims on the non-bank financial sector.

Before proceeding to describe the method and results, it is worth bear in mind that the TCTF problem is not necessarily related to the problems of Too-Big-to-Fail (TBTF) or Too-Many-to-Fail (TMTF). An institution considered to be TBTF is not necessarily TCTF. For instance, in a banking system where retail deposits are the main funding source, interbank exposures are negligible, and there is deposit insurance, any bank with a large share of deposits could be TBTF owing to the costs associated with deposit insurance in the case the bank defaults. The failure of such a bank, however, may not have a direct negative impact on other banks. Moreover, stronger banks may benefit from a flight to quality from depositors. In contrast, the business and operational framework under which banks operate may be such that the failure of a relatively small institution may put all institutions in the system at risk. An example in point is the distress experienced by the payment and settlement system following the liquidation of Herstatt bank in 1974.

The TMTF problem is associated with the simultaneous failure of a large number of institutions owing to herd behavior (Acharya and Yorulmazer, 2007). The herd behavior is prompted by the observation that an individual institution, unless deemed TBTF, may be allowed to fail by the supervisory agency. It is in their best interest, therefore, for small institutions to coordinate their behavior such that, under adverse circumstances, a large number of them fail simultaneously. The TMTF problem, therefore, is different from the TCTF problem since the failure of one institution does not cause other institutions' failures.

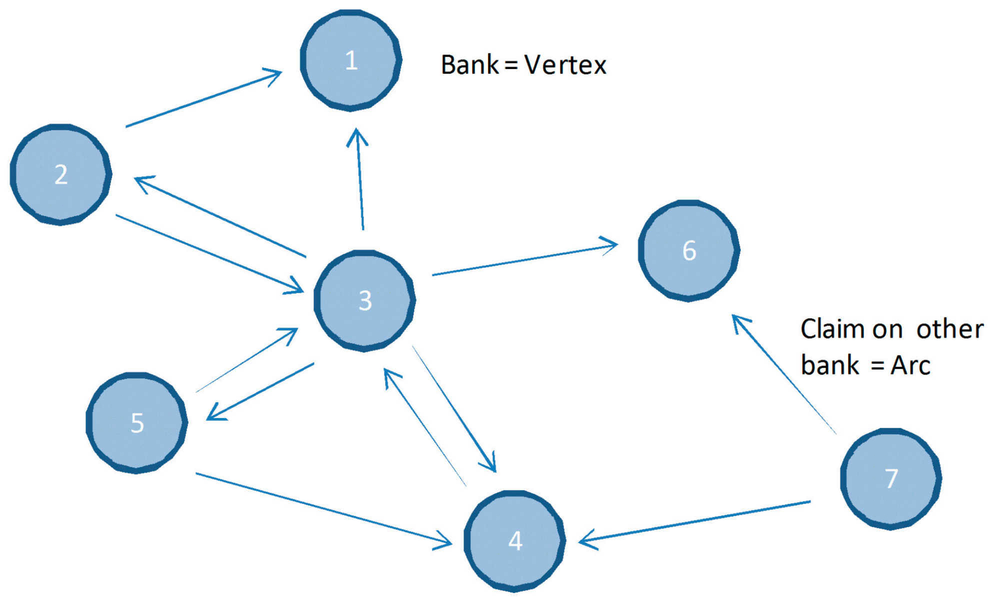
II. Balance Sheet-Based Network Analysis

A financial or banking system can be visualized as a network of institutions (or vertices) linked to each other through directed edges (or arcs). In graph theory, the combination of a set of vertices and a set of arcs constitutes a directed graph or digraph. Figure 1 depicts the digraph of a stylized banking system, consisting of seven banks that are represented by the vertices numbered from 1 to 7. Claims on a bank are represented by inbound arcs to the respective vertex. For instance, bank 7 has claims on banks 4 and 6.

The mapping of a financial system into a digraph is useful from a supervisory and financial stability perspective. The digraph provides a simple visualization of the different linkages across institutions that, for instance, could help guide the design of the perimeter of regulation. Once the mapping has been established, different analytical tools can be brought in to analyze the stability of the financial system. This paper describes a simple set of tools, balance sheet-based network analysis, which builds on simple balance sheet accounting identities and simulations to analyze different types of shocks affecting the banking system.

A more sophisticated set of tools, graph theory-based models, are described in some detail in Appendix 1.[3]

Figure 1. A digraph representation of a banking system.



Balance sheet-based network analysis models rely on financial statements data to construct the matrix of cross-claims across institutions, and use simulation to analyze how shocks affecting one institution are propagated through the banking system. Among others, balance sheet-based models include those of Sheldon and Maurer (1998), Furfine (2003), Upper and Worm (2004), Wells (2004), Elsinger, Lehar, and Summer (2006), and more recently, Aikman et al (2009) and Chan-Lau, Espinosa, Giesecke, and Solé (2009). Though definitely more rudimentary than network models based on graph theory, balance sheet-based models are relatively easy to implement, and the results have a clear economic interpretation which facilitates communication with senior decision makers.[4]

[3] It is important to distinguish between the usage of the term "network analysis" in economics and social sciences, and the usage in other disciplines. In economics and social sciences, network analysis refers to the analysis of the properties of systems that can be mapped into graphs using *graph theory* and *combinatorics*, e.g. Bollobas (1998) and Durrett (2007). In other disciplines, network analysis focuses on optimizing flows between different nodes (or vertices), a problem closely related to *optimization theory*, e.g. Ahuja, Magnanti, and Orlin (1993). For an early application of the latter type of techniques to financial systems, see Nagurney and Siokos (1997).

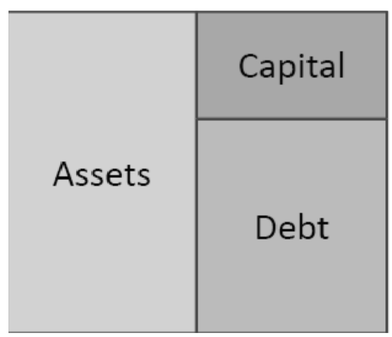
[4] An alternative approach not described here is the use of agent-based computational modeling, as in Markose et al (2009).

A. The Basic Accounting Identity

Balance sheet-based models start from the observation of the equality between the asset side and the liability side of the balance sheet of a bank or financial institution (Figure 2). On the asset side of the balance sheet the bank records its claims on other financial institutions, corporations, and households, such as loans, receivables, equity shares, and debt securities. On the liability side, the bank records what it owes to its shareholders, i.e. the bank's equity, and to different creditors, including depositors, plus other items which together with the bank's equity constitute the bank capital.[5]

The bank's capital is the first cushion against declines in the value of the assets of the bank. If the decline in asset value exceeds the value of the bank's capital, the bank defaults as its capital disappears.[6] The default of the bank ripples through the banking system as the bank defaults on its liabilities or through the forced withdrawing of the funding it has extended to other banks in the system. Losses from claims on the defaulted banks erode the capital of the surviving banks. In addition, funding withdrawals, if not fully replaced, could force fire-sale of assets at depressed values and reduce the asset and equity value of the selling bank, while forcing mark-to-market losses in other banks.

Figure 2. A simplified bank balance sheet



Balance sheet-based network analysis models can accommodate a number of different shocks, namely, credit shocks, funding shocks, risk-transfer shocks and different

[5] The bank capital is equal to the sum of Tier 1 capital and Tier 2 capital. Tier 1 capital includes permanent shareholders' equity plus disclosed reserves, including retained earnings less goodwill. Tier 2 capital includes general provisions and loan loss reserves, revaluation reserves, hybrid capital instruments, subordinated term debt and undisclosed reserves less investments in unconsolidated financial subsidiaries and in the capital of other financial institutions.

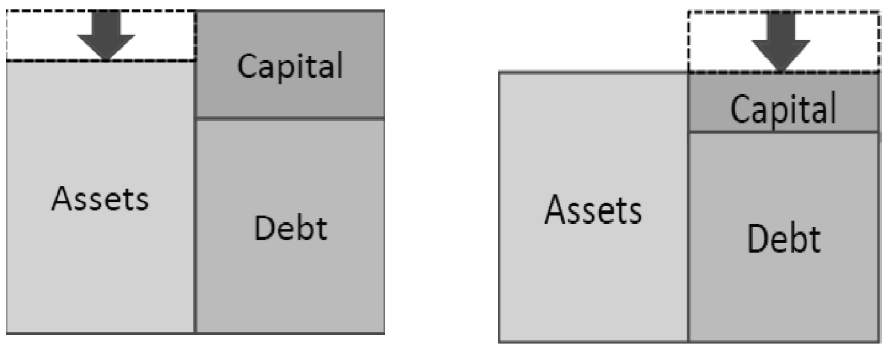
[6] It can be argued, however, that the relevant event from a supervisory perspective is not the default of the bank per se but when rather the event that the bank's capital falls below the regulatory minimum level. The analysis using the tools in this paper, in this case, could be easily extended by assuming that a bank "defaults" occurs when capital is less than the regulatory capital rather than when capital vanishes. The simplest way to incorporate this situation into the analysis is by reducing the amount of capital in the bank by the minimum regulatory capital and keeping the original definition of default intact.

combinations of the above mentioned shocks. The next paragraphs offer a diagrammatic explanation of the concepts underlying the framework presented in Chan-Lau, Espinosa, Giesecke and Solé (2009). Readers interested in the full details of the methodology, including the equations, should refer to this paper.

B. Credit Shocks

Credit shocks are associated with losses on the asset side of the balance sheet.[7] Claims on other banks are recorded as an asset. When other banks default, the value of the claim is reduced since it is unlikely that the creditor bank recovers the claim's full value, or in other words, the loss given default is strictly positive, or equivalently, the recovery ratio is less than one hundred percent. In consequence, the capital of the bank declines (Figure 3).

Figure 3. Credit shock



The bank defaults if the losses exceed the value of its capital:

(1) $$\text{Capital} - \sum \text{Claims on defaulted banks} \times \text{Loss Given Default} < 0$$

A simple simulation can determine whether the default of a bank can trigger a cascade of failures. After setting the default of a specific bank, the equation above is used to see whether losses to other banks could trigger their default. If another bank defaults, its defaulted claims are taken away from the capital of the surviving banks and again, it is necessary to check whether another bank defaults as a consequence of the new default. The previous step is repeated until no other bank defaults. When only credit shocks are analyzed, it is assumed that other banks can replace funding from defaulted banks without major difficulties.

C. Funding Shocks

Funding shocks are associated with the sudden withdrawal of funding and constitute a liability shock. Because assets need to be supported by liabilities, a sudden shortfall in funding sources leads to a reduction of the balance sheet of the bank if it cannot find

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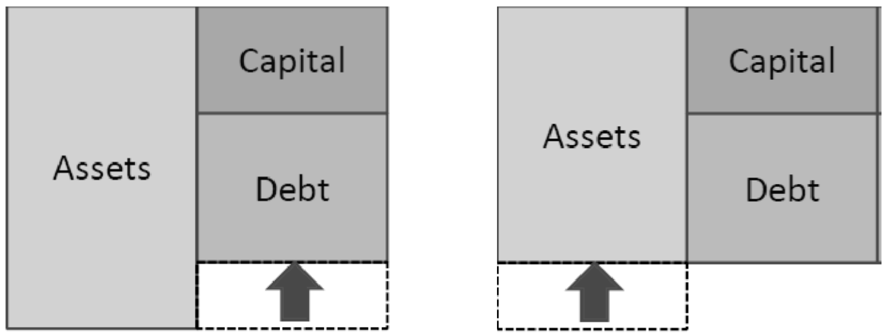
[7] This is the case considered in Sheldon and Maurer (1998), Furfine (2003) and Wells (2004).

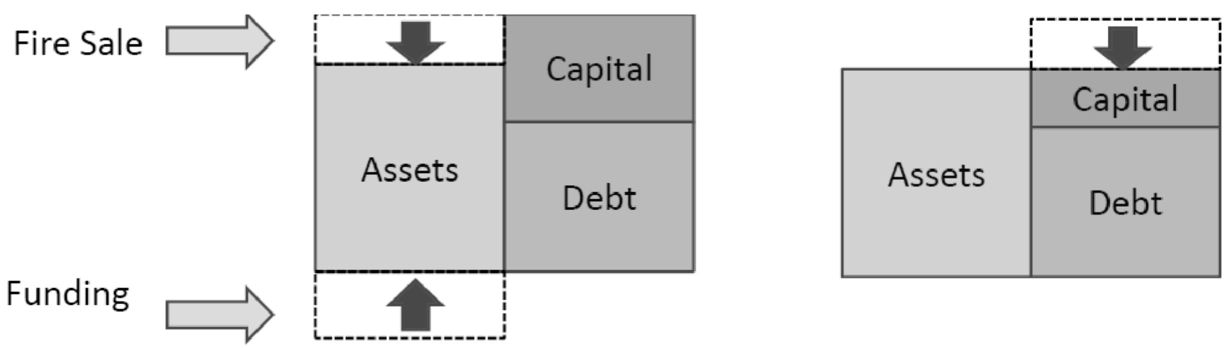
alternative funding sources. Under normal market conditions the amount of assets the bank needs to sale is equal to the loss of funding and the bank capital is not affected (Figure 4). Furthermore, the leverage of the bank declines lowering the probability that it may become insolvent.

Figure 4. Funding shock under normal market conditions



The bank, however, may be forced to liquidate assets at below face values under fire sale conditions, especially if the market is undergoing a liquidity shortage, the assets are very illiquid, or if the bank holds large positions in certain assets. In the latter case, if other banks and market participants know that the affected bank needs to liquidate certain assets, they may collude to mark these assets down in order to take advantage of the bank's distress.[8] In this case, the bank may need to liquidate assets in excess of the funding withdrawn from the bank. These losses are reflected in capital losses (Figure 5).

Figure 5. Funding shock under stressed market conditions



For some banks, funding losses could exceed their capital and cause their default. In this case, the initial funding shock leads to both subsequent credit and funding shocks as other banks default. The following inequality determines when a bank defaults:

[8] See Hagan (2009) for a vivid narrative of the problems related to fire sale of assets and the mark down of positions faced by Bear Stearns in 2008.

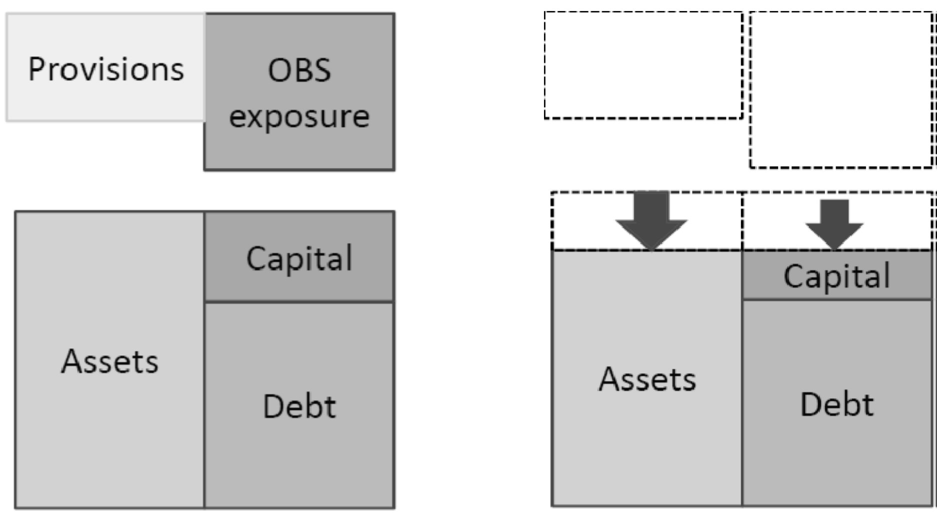
(2) $$\text{Capital} - \sum \text{Claims on defaulted banks} \times \text{loss given default} - \sum \text{funding withdrawal} \times (\text{1-replacement ratio}) \times \text{fire sale loss ratio} < 0$$

As in the pure credit shock case, simulations can be used to determine how resilient the system is to funding shocks affecting the system banks.

D. Risk Transfer Shocks and Off-Balance Sheet Exposures

Risk transfer shocks are associated with losses from off-balance sheet (OBS) exposures. Analyzing these losses in a balance-sheet framework requires additional information related to the size of the OBS sheet exposure and the provisions held against it by the bank. Once this information is obtained, the analysis of a risk transfer shock can be analyzed in an extended balance sheet framework (Figure 6).

Figure 6. Risk transfer shock



When the bank experiences losses in its OBS exposure, it first uses its OBS provisions as a buffer. When the loss exceeds the provisions, the bank suffers capital losses, and if the capital losses are large enough, the bank defaults:

(3) $$\text{Capital} - \text{Off-balance sheet exposure} + \text{provisions} < 0.$$

It goes without saying that a bank default owing to an OBS exposure shock could trigger subsequent credit and funding shocks in the banking system and lead to the failure of other banks. As in the case of credit shocks and funding shocks, simple simulations can be used to analyze the impact of OBS losses on the banking system.

III. Balance Sheet-Based Network Analysis in Practice

This section illustrates the use of balance sheet-based network analysis in the assessment of TCTF or interconnectedness risk in the global banking system and in the domestic banking system in Chile, an advanced emerging market economy closely integrated into the financial system.[9]

Only credit shocks, funding shocks, and simultaneous credit and funding shocks are considered in the analysis. The following assumptions are used to calculate the results: (1) the loss given default in the credit shock scenario is set equal to 70 percent; and (2) in the case of funding shocks, only 40 percent of the funding can be replaced forcing the sale of assets at fire sale prices 50 percent below book value.

Risk transfer shocks are not considered in the analysis of the global banking system since the aggregate data only approximates roughly the interbank exposure across countries. Furthermore, up to date there are no publicly available data sources on risk transfers at the individual institution level. Given the data limitations, it may not be proper to add another layer of approximations to try to infer risk transfer between banks. In the analysis of the Chilean domestic banking system, credit risk transfers between institutions are negligible.

One important caveat in interpreting the results is that in all the calculations, it is assumed that either a bank or banking system fails, which is a very low probability event under the current environment, or that a sudden withdrawal of funding takes place, which is also a low probability event. Therefore, the results should be interpreted as those corresponding to very extreme adverse scenarios.

A. TCTF Risk Analysis in Mature and Emerging Market Countries Banking Systems

The analysis of TCTF risk from the perspective of the global banking system relies on the availability of data on cross-country claims across different bank jurisdictions. Currently, the BIS is the only institution that compiles cross-border banking statistics. In particular, consolidated banking statistics, constructed using central bank reports in 42 countries, comprise a country's aggregate banking system financial claims on the rest of the world.[10] These statistics have been widely used to assess the risks exposures of lenders' national banking systems to other countries but there is wide consensus that it is necessary to improve data collection on interbank exposures (FSB and IMF, 2009).

Consolidated banking statistics are reported on an immediate borrower and an ultimate borrower basis. Figures reported on an immediate borrower basis correspond to contractual claims by the head office of a bank and all its branches and are assigned to the home country

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[9] All calculations in this section were performed using the Excel-VBA programs described in Chan-Lau (2010).

[10] The consolidated banking statistics are available at http://www.bis.org/statistics/consstats.htm. See BIS (2008) for a detailed guide to the statistics and several issues of the BIS Quarterly Review.

of the head office. Since banks have access to risk transfer or risk mitigation instruments and techniques, cross-country claims could actually differ from contractual claims. Figures reported on an ultimate borrowing basis account for the impact of risk transfers on contractual claims.

In principle the difference between claims on an immediate borrower basis and ultimate borrower basis can be used to infer the risk transfer exposures. The analysis here refrains from performing such inference since the aggregate data is only an approximation to interbank exposures as it includes, in addition to claims on banks, claims on non-bank financial institutions, non-financial institutions and households. Under these circumstances, it was not considered appropriate to add another layer of approximation by inferring risk transfer exposures.[11]

Balance sheet-based network analysis was used to evaluate TCTF risk in banking systems with BIS consolidated claims data on an immediate borrower basis for twenty countries in the first and third quarter of 2009.[12] The country sample includes emerging market countries: Brazil, Chile and Mexico; and in mature market countries: Austria, Belgium, Canada, Denmark, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Data on total capital in the banking system in the countries analyzed was obtained from different sources including the European Central Bank statistics and different issues of banking system supplements published by Moody's Investor Services.

Table 1 shows what banking systems may be at risk due to shocks affecting banks headquartered in other countries. For the purpose of the analysis, it is assumed that a banking system fails if losses from the shocks exceed the aggregate capital in the system since aggregated data does not allow identifying specific banks that may fail as a consequence of the shock. Imposing the above banking system failure condition is akin to assume that claims and liabilities of failed banks are taken over by the surviving banks in the country. The results are complemented by Table 2, which shows capital losses in national banking systems due to shocks to other jurisdictions.

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[11] Readers interested in how to approximate risk transfers should refer to Chan-Lau, Espinosa, Giesecke and Solé (2009).

[12] The choice of consolidated banking statistics presumes that profits, as well as losses, are consolidated and ultimately borne by the head office of the bank. However, if foreign banks operate mainly as subsidiaries in host jurisdictions, the subsidiaries are required to operate as stand-alone institutions and to hold their own capital. In many instances, domestic supervisors would demand that foreign subsidiaries are ring-fenced, so that the head office or a related subsidiary in other country cannot have recourse to its capital. Under such circumstances, it could be argued that the analysis should be based on the BIS locational banking statistics. These statistics report claims and liabilities of banks offices in the countries they operate. Locational banking statistics are available at http://www.bis.org/statistics/bankstats.htm

Table 1. Global banking system: number of potential failures

The table shows potential banking system failures induced by shocks originated in banking systems in other countries. The calculations use BIS cross-border claims data on an immediate borrower basis.

Panel A: First Quarter 2009

	Type of shock, and originating banking system									
	Credit		Funding	Credit and funding						
	UK	US	Spain	Denmark	France	Germany	Netherlands	Spain	UK	US
Banking system failure in:										
Austria									Yes	Yes
Belgium	Yes	Yes			Yes	Yes	Yes		Yes	Yes
Brazil										
Canada		Yes							Yes	Yes
Chile			Yes					Yes	Yes	Yes
Denmark	Yes	Yes				Yes			Yes	Yes
France	Yes	Yes							Yes	Yes
Germany	Yes	Yes							Yes	Yes
Greece									Yes	Yes
Ireland	Yes	Yes				Yes			Yes	Yes
Italy									Yes	Yes
Japan		Yes							Yes	Yes
Mexico									Yes	Yes
Netherlands	Yes	Yes			Yes	Yes			Yes	Yes
Portugal		Yes							Yes	Yes
Spain		Yes							Yes	Yes
Sweden	Yes	Yes		Yes		Yes			Yes	Yes
Switzerland	Yes	Yes							Yes	Yes
UK		Yes								Yes
US									Yes	
Total, excluding originating country	8	13	1	1	2	5	1	1	18	18

Panel B: Third Quarter 2009

	Type of shock, and originating banking system									
	Credit			Funding	Credit and funding					
	Denmark	UK	US	Spain	Denmark	France	Germany	Spain	UK	US
Banking system failure in:										
Austria			Yes				Yes		Yes	Yes
Belgium		Yes	Yes			Yes	Yes		Yes	Yes
Brazil										
Canada			Yes				Yes		Yes	Yes
Chile				Yes			Yes	Yes	Yes	Yes
Denmark		Yes	Yes				Yes		Yes	Yes
France		Yes	Yes				Yes		Yes	Yes
Germany		Yes	Yes						Yes	Yes
Greece							Yes		Yes	Yes
Ireland		Yes	Yes				Yes		Yes	Yes
Italy			Yes				Yes		Yes	Yes
Japan			Yes				Yes		Yes	Yes
Mexico							Yes		Yes	Yes
Netherlands		Yes	Yes			Yes	Yes		Yes	Yes
Portugal		Yes	Yes				Yes		Yes	Yes
Spain		Yes	Yes				Yes		Yes	Yes
Sweden	Yes	Yes	Yes		Yes		Yes		Yes	Yes
Switzerland		Yes	Yes				Yes		Yes	Yes
UK			Yes				Yes			Yes
US							Yes		Yes	
Total, excluding originating country	1	10	15	1	1	2	18	1	18	18

Source: BIS, ECB, Moody's Investor Services, and author's calculations.

Table 2. Global banking system: potential capital losses, in percent

The table shows capital losses induced by shocks affecting other countries as percent of a banking system total capital. The calculations use BIS cross-border claims data on an immediate borrower basis.

Panel A: First quarter, 2009

Capital losses in:	Austria	Belgium	Brazil	Canada	Chile	Denmark	France	Germany	Greece	Ireland	Italy	Japan	Mexico	Netherlands	Portugal	Spain	Sweden	Switzerland	UK	US
Austria		3	0	1	0	3	26	75	3	4	37	2	0	13	1	5	1	9	100	100
Belgium	6		1	8	0	9	100	100	5	58	40	10	0	100	7	39	4	12	100	100
Brazil	1	0		1	1	1	5	5	0	0	1	2	0	2	1	21	0	3	58	58
Canada	0	4	1		0	2	18	26	0	2	1	12	0	12	0	1	1	5	100	100
Chile	0	1	5	0		1	22	33	0	0	3	4	1	14	0	100	1	1	100	100
Denmark	1	5	0	1	0		24	100	0	19	2	4	0	12	1	5	86	5	100	100
France	3	18	2	3	0	5		88	8	8	51	28	1	36	4	22	2	9	100	100
Germany	16	8	1	6	1	16	77		5	26	41	14	1	38	6	33	9	12	100	100
Greece	3	4	0	0	0	1	52	41		5	5	3	0	12	3	1	1	28	100	100
Ireland	5	20	0	6	0	11	65	100	5		31	15	0	36	7	21	4	5	100	100
Italy	20	5	0	1	0	1	54	82	2	7		3	0	15	1	8	1	3	100	100
Japan	1	2	1	4	0	2	25	28	0	3	4		1	8	0	3	1	5	100	100
Mexico	0	0	0	0	0	0	21	17	0	0	1	5		12	0	100	0	4	100	100
Netherlands	8	90	6	19	3	13	100	100	7	20	45	20	7		7	68	5	19	100	100
Portugal	2	6	7	0	0	2	45	72	7	22	7	1	0	22		69	1	6	100	100
Spain	1	5	20	1	8	2	40	51	0	5	10	2	23	18	16		1	2	100	100
Sweden	2	5	1	2	0	100	31	100	1	7	4	5	0	16	1	7		8	100	100
Switzerland	7	8	7	11	0	10	76	92	24	8	11	44	2	29	2	8	5		100	100
UK	2	7	3	8	0	5	50	77	1	22	8	13	2	20	2	21	3	10		100
US	1	6	3	21	1	4	48	67	1	8	5	45	7	20	1	10	3	27	100	

Panel B: Third quarter, 2009

	Credit and funding shock originated in:																			
Capital losses in:	Austria	Belgium	Brazil	Canada	Chile	Denmark	France	Germany	Greece	Ireland	Italy	Japan	Mexico	Netherlands	Portugal	Spain	Sweden	Switzerland	UK	US
Austria		5	0	1	0	4	30	100	4	7	41	2	0	17	2	7	2	10	100	100
Belgium	9		1	6	0	10	100	100	7	64	46	11	0	100	8	43	3	12	100	100
Brazil	1	1		0	3	1	7	76	0	0	0	3	0	3	2	28	0	3	76	76
Canada	1	3	0		0	2	20	100	0	7	1	13	0	13	0	1	1	5	100	100
Chile	0	1	17	0		1	22	100	0	0	2	3	1	13	0	100	1	1	100	100
Denmark	1	5	0	1	0		25	100	0	19	3	4	0	11	1	4	98	8	100	100
France	3	18	3	3	0	6		100	8	10	56	29	1	37	4	24	3	9	100	100
Germany	18	10	1	5	1	16	85		6	27	44	16	1	41	6	35	9	13	100	100
Greece	4	5	0	0	0	1	56	100		6	5	5	0	13	6	1	1	36	100	100
Ireland	6	21	0	9	0	12	71	100	5		33	17	0	39	9	22	4	6	100	100
Italy	21	5	0	1	0	2	57	100	1	7		4	0	15	2	9	1	3	100	100
Japan	1	2	2	5	0	3	27	100	1	4	5		1	8	0	3	2	6	100	100
Mexico	0	0	0	0	0	1	17	100	0	0	1	5		9	0	100	0	4	100	100
Netherlands	8	87	7	23	3	12	100	100	6	21	46	20	5		9	72	6	20	100	100
Portugal	2	7	8	0	0	3	54	100	12	28	10	2	0	27		78	2	5	100	100
Spain	2	5	26	0	9	2	44	100	0	5	12	2	23	19	19		1	2	100	100
Sweden	2	4	1	3	0	100	34	100	1	7	4	7	1	16	1	7		8	100	100
Switzerland	9	9	8	11	0	14	77	100	31	9	13	55	2	32	2	9	5		100	100
UK	2	7	5	9	0	6	57	100	1	24	8	16	2	22	2	23	3	11		100
US	1	6	5	23	1	5	55	100	1	9	6	50	7	22	1	11	3	24	100	

Source: BIS, ECB, Moody's Investor Services, and author's calculations.

In general, if shocks originate in the banking systems in the UK and the US they may have the potential to cause failures in the banking systems in most countries during 2009. By this standard, banks headquartered in the UK and the US could be TCTF from a global perspective. Similarly, systemic risk from shocks originated in the banking system in Germany appears to have increased twice-fold in the six months period from March 2009 to September 2009.

In Europe, shocks that originate in the French banking system could potentially have a large impact on banking systems in Belgium and the Netherlands. It is also apparent that Swedish banks could be exposed to negative shocks to Danish banks. Among the Latin American countries analyzed, the banking system in Chile is the most exposed to funding risks from Spanish banks. Interestingly, the Brazilian banking system appears robust enough to withstand the ripple effect from adverse shocks affecting major banking systems.

Table 3. Global banking system: Too-Connected-to-Fail risk and vulnerability measures

The table shows TCTF vulnerability and risk measures due to joint credit and funding shocks. The TCTF vulnerability measure is the average capital loss suffered by the banking system in the country listed in the column due to shocks affecting banking systems in other countries. The TCTF risk measure is the average capital loss induced by the failure of the banking system listed in the first column on other banking systems.

	First quarter 2009		Third quarter 2009	
	TCTF vulnerability	TCTF risk	TCTF vulnerability	TCTF risk
Austria	20	4	23	5
Belgium	37	10	38	11
Brazil	8	3	15	4
Canada	15	5	19	5
Chile	20	1	24	1
Denmark	24	10	25	10
France	26	46	27	49
Germany	27	66	28	99
Greece	19	4	23	4
Ireland	28	12	29	13
Italy	21	16	23	18
Japan	15	12	19	14
Mexico	19	2	23	2
Netherlands	39	23	39	24
Portugal	25	3	28	4
Spain	21	29	25	30
Sweden	26	7	26	8
Switzerland	29	9	31	10
UK	19	98	21	99
US	20	98	23	99

Source: BIS, ECB, Moody’s Investor Services, and author’s calculations.

Some simple measures can be used to assess the vulnerability of a national banking system to external shocks, and the risk it poses to the banking systems in other countries. For instance, the average capital loss experienced by a national banking system due to shocks in other countries is a measure of TCTF vulnerability. Similarly, the average losses shocks in a national banking system induce in other countries is a measure of TCTF risk. These measures are reported in Table 3 for simultaneous credit and funding shocks. For banks headquartered in Austria, for instance, they lose on average 23 percent of its capital due to shocks in other banking systems. On the other hand, shocks to banks headquartered in Austria induce average capital losses of around 5 percent in other countries.

From a TCTF perspective, the most vulnerable banking systems are those of Belgium, the Netherlands and Switzerland, while the riskiest are those based in Germany, the United Kingdom and the United States. Both TCTF risks and vulnerabilities increased during 2009. From a financial stability perspective, note that the continuous updating of a matrix of TCTF risks and vulnerabilities such as the one presented in Table 3 could be a useful input for financial surveillance and the setup of a dynamic risk scoring system.

Finally, by recalling the digraph representation of a financial system network in Figure 1, it is clear that the absence of direct exposure between two banking systems does not preclude their simultaneous failure if both are connected to a banking system that fails. For instance, in Figure 1 the failure of Bank 1 could prompt the failure of Bank 4 if the failure of the former induces the failure of Bank 3. Therefore, the failure of one banking system can trigger a default cycle. Take for instance, the hypothetical default cycle triggered by a credit shock originated in the banking system in the UK (Table 1, first column). In a first round, the banking systems of Ireland, the Netherlands and Switzerland are affected. In a second round, the banking systems of Belgium and Germany are affected; in a third round, the banking system in France fails, and the cumulative impact affects the banking system in Denmark in the last round.

B. Chile: TCTF Risk Analysis in an Advanced Emerging Market Economy

This section uses balance sheet-based network analysis to evaluate the TCTF risk in Chile, an advanced emerging market economy. Data on claims and liabilities of individual banks vis-à-vis the central bank, foreign banks, and the corporate, nonbank financial and household sectors is available from the Monthly Report on Financial Institutions published by the Banking Supervisory Agency (SBIF) with a one to two-month lag.[13]

The monthly report covers twenty domestic banks and foreign bank subsidiaries, and five foreign bank branches. For each supervised financial institution, the report states the total amount the institution owes to other banks in the system but not to specific institutions. Similarly, the report states the total claims the institution has on other banks in the system but does not disaggregate claims by individual banks.

In the absence of more detailed interbank exposure data, the matrix of interbank exposures was constructed by assuming that the amount a bank owes in the system is divided equally among all banks reported as having claims on other banks. The above shortcut is analogous

[13] http://www.sbif.cl/sbifweb/servlet/InfoFinanciera?indice=4.1&idCategoria=2151&tipocont=2359

to assume that banks attempt to diversify their interbank exposure as much as possible. This is not the only possible way to construct the matrix of interbank exposures. One alternative is to assign the amount owed by the bank proportionally to the size of the claimant banks. Another alternative is the use entropy techniques, as done for instance by Sheldon and Maurer (1998) and Wells (2002).

Similarly, there is no publicly available detailed information on assets and liabilities vis-à-vis individual foreign banks or specific foreign banking systems. In the analysis presented below, foreign banks are modeled as a single sector. The assumption of a single foreign banking sector errs on the conservative side as it implies that all foreign banks will be simultaneously affected by the same shocks. For instance, a funding shock implies that all foreign banks withdraw funding to banks operating in Chile at the same time.

In addition to domestic and foreign banks, the banking system network was augmented to include the Central Bank of Chile (BCCH), the non-bank financial institutions sector, the corporate sector, and the household sector. The BCCH is included since it has been an important provider of liquidity and financing to the banking sector in the aftermath of the 2008/9 global financial crisis. The inclusion of the central bank in the network is relatively straightforward since there are bank-specific data on the claims and liabilities it holds vis-à-vis domestic banks.

The importance of non-bank financial institutions, especially pension funds and mutual funds, has increased in the wholesale funding market. In the case of non-bank financial institutions, the monthly report provides data on the deposits they held on individual banks but there is no data on what they may owe to banks. So, in the analysis, non-bank financial institutions appear only as creditors to the banking system.

Corporations account for a substantial share of bank claims. Claims on corporates are constructed using data on corporate loans and receivables. In the analysis, the corporate sector appears only as a debtor since there are no data on corporates' claims on the banking system. Finally, households play a large role both on the funding side, through deposits, as well as on the asset side, as borrowers. Data on household deposits and consumer loans is used to include the household sector in the network.

Table 4 and 5 report the results of the analysis in January, July, and December 2009. Table 4 reports the number of potential defaults and Table 5 the average capital losses.

Domestic interbank exposure is relatively unimportant as the default of a single bank would not lead to further defaults (Table 4). The average capital losses reported in Table 5 provides further support while pointing towards a reduction of interbank exposures during 2009. For instance, in January 2009 the hypothetical default of Bank 5 and Bank 3 would have triggered average capital losses of 10.2 percent and 7.4 percent respectively, but in December 2009 these losses declined to 1.1 percent and 0.7 percent respectively. Against this trend, risks from Bank 4 appear to have trended upwards. Average capital losses induced by its hypothetical default have increased to 6.9 percent from 0.3 percent. The hypothetical capital losses are mainly concentrated on Bank 12 (35 percent), Bank 21 (54 percent), and Bank 25 (47 percent).

A close examination of the results in Table 4 and 5 suggests that domestic banks have been reducing their claim exposure to the corporate and household sector during 2009. The number of banks that could default following a negative credit shock from the system-wide collapse of the corporate sector declined to 14 from 17 at the beginning of the year while average capital losses declined to 76 percent from 82 percent. Similarly, average capital losses following defaults on household loans fell to 59 percent from 68 percent.

Table 4. Chile: Potential number of induced defaults

The table shows the number of induced bank defaults due to credit shocks, funding shocks, and the joint realization of credit and funding shocks.

	Type of shock								
Number of bank failures when	Credit shock			Funding shock			Credit and funding shock		
shock comes from:	Jan. 2009	Jul. 2009	Dec. 2009	Jan. 2009	Jul. 2009	Dec. 2009	Jan. 2009	Jul. 2009	Dec. 2009
Bank 1	0	0	0	0	0	0	0	0	0
Bank 2	0	0	0	0	0	0	0	0	0
Bank 3	0	0	0	0	0	0	0	0	0
Bank 4	0	0	0	0	0	0	0	0	0
Bank 5	0	0	0	0	0	0	0	0	0
Bank 6	0	0	0	0	0	0	0	0	0
Bank 7	0	0	0	0	0	0	0	0	0
Bank 8	0	0	0	0	0	0	0	0	0
Bank 9	0	0	0	0	0	0	0	0	0
Bank 10	0	0	0	0	0	0	0	0	0
Bank 11	0	0	0	0	0	0	0	0	0
Bank 12	0	0	0	0	0	0	0	0	0
Bank 13	0	0	0	0	0	0	0	0	0
Bank 14	0	0	0	0	0	0	0	0	0
Bank 15	0	0	0	0	0	0	0	0	0
Bank 16	0	0	0	0	0	0	0	0	0
Bank 17	0	0	0	0	0	0	0	0	0
Bank 18	0	0	0	0	0	0	0	0	0
Bank 19	0	0	0	0	0	0	0	0	0
Bank 20	0	0	0	0	0	0	0	0	0
Bank 21	0	0	0	0	0	0	0	0	0
Bank 22	0	0	0	0	0	0	0	0	0
Bank 23	0	0	0	0	0	0	0	0	0
Bank 24	0	0	0	0	0	0	0	0	0
Bank 25	0	0	0	0	0	0	0	0	0
Central bank	0	0	0	0	0	0	0	0	0
Foreign Banks	0	0	0	1	1	1	1	1	1
Non-bank financial institutions	0	0	0	2	1	4	2	1	4
Corporates	17	16	14	n.a.	n.a.	n.a.	17	16	14
Households	14	12	12	17	17	16	17	17	16

Source: SBIF and author's calculations.

Domestic banks have increased their reliance on wholesale funding from non-bank financial institutions in 2009. In December 2009, a hypothetical sudden withdrawal of non-bank financial deposits could lead to problems in four banks (Bank 16, Bank 17, Bank 18, and Bank 20) up from 2 in January 2009 (Bank 18 and Bank 20).

Another important funding source during 2009 has been the central bank. On average, capital losses would be approximately 3 percent if central bank funding were not available. These losses, however, are heavily concentrated in a handful of institutions. As of December 2009, the institutions more affected by reduced funding from the central bank are Bank 4 (32 percent capital loss), Bank 11 (24 percent) and Bank 13 (22 percent).

Table 5. Chile: Average capital losses, in percent

The table shows the average bank capital losses suffered due to credit shocks, funding shocks, and the joint realization of credit and funding shocks as percent of the institution's total capital.

Average bank capital losses when shock comes from:	Credit shock			Funding shock			Credit and funding shock		
	Jan. 2009	Jul. 2009	Dec. 2009	Jan. 2009	Jul. 2009	Dec. 2009	Jan. 2009	Jul. 2009	Dec. 2009
Bank 1	0.0	1.1	0.0	0.0	0.0	0.0	0.0	1.1	0.0
Bank 2	4.4	0.0	0.1	0.0	0.0	0.0	4.4	0.0	0.1
Bank 3	7.4	1.7	0.6	0.0	0.0	0.0	7.4	1.7	0.7
Bank 4	0.3	3.1	5.7	0.2	0.0	0.0	0.5	3.1	6.9
Bank 5	10.2	1.0	0.8	0.0	0.1	0.1	10.2	1.1	1.1
Bank 6	3.2	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0
Bank 7	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Bank 8	0.2	0.0	0.0	0.2	0.1	0.0	0.4	0.1	0.0
Bank 9	0.0	0.2	0.0	0.2	0.0	0.0	0.2	0.2	0.0
Bank 10	0.3	0.0	0.5	0.2	0.1	0.1	0.5	0.1	0.7
Bank 11	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
Bank 12	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Bank 13	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Bank 14	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
Bank 15	0.5	1.0	0.5	0.2	0.0	0.0	0.7	1.0	0.6
Bank 16	0.0	2.8	0.0	0.0	0.1	0.1	0.0	2.9	0.1
Bank 17	2.6	5.8	0.0	0.2	0.0	0.0	2.8	5.8	0.0
Bank 18	1.0	0.4	0.1	0.2	0.1	0.1	1.2	0.5	0.2
Bank 19	2.4	0.6	0.0	0.0	0.1	0.1	2.4	0.7	0.1
Bank 20	0.3	0.1	0.0	0.2	0.1	0.1	0.5	0.2	0.1
Bank 21	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Bank 22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bank 23	0.0	0.1	0.0	0.2	0.1	0.0	0.2	0.2	0.0
Bank 24	0.0	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.0
Bank 25	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Central bank	n.a.	n.a.	n.a.	2.9	3.9	3.5	5.0	7.0	4.7
Foreign Banks	7.8	3.0	5.3	17.3	13.4	16.8	25.1	16.4	22.2
Non-bank financial institutions	0.0	0.0	0.0	43.1	41.7	43.7	43.1	41.7	43.7
Corporates	82.1	76.6	75.8	n.a.	n.a.	n.a.	83.1	77.0	76.1
Households	68.0	64.5	58.5	86.5	85.9	85.4	86.5	85.9	85.5

Source: SBIF and author's calculations.

Table 6 reports TCTF risk and vulnerability measures for Chilean financial institutions. Overall, in 2009 TCTF vulnerability has been higher for foreign bank branches owing to their large interbank exposures relative to their capital. TCTF risk related to Bank 5 and Bank 17 has declined during the year but it increased substantially for Bank 4.

Finally, Table 7 reports excess capital losses in the banking system, as percent of total aggregate capital, due to shocks originated in banks operating in Chile. Excess capital losses measure the capital losses in the system excluding the losses of the bank that triggered the shocks. This measure is a TCTF risk measure closely related to the concepts of incremental contribution to risk introduced in Chan-Lau (2009) and marginal contribution to risk introduced by Tarashev, Borio, and Tsatsaronis (2009).

Table 6. Chile: Too-Connected-to-Fail risk and vulnerability measures

The table shows TCTF vulnerability and risk measures due to simultaneous credit and funding shocks. For the banks listed in the first column, the TCTF vulnerability is measured as the average capital loss the bank suffers from shocks to other banks in the system. The TCTF risk is measured as the average capital loss the bank induces on other banks in the system.

	TCTF Vulnerabilty			TCTF Risk		
	January 2009	July 2009	December 2009	January 2009	July 2009	December 2009
Bank 1	0.0	0.1	0.0	0.0	1.1	0.0
Bank 2	0.2	0.0	0.0	4.4	0.0	0.1
Bank 3	0.3	0.1	0.0	7.4	1.7	0.7
Bank 4	0.1	0.1	0.2	0.5	3.1	6.9
Bank 5	0.2	0.1	0.1	10.2	1.1	1.1
Bank 6	0.8	0.0	0.0	3.2	0.0	0.0
Bank 7	1.3	0.6	0.7	0.2	0.1	0.1
Bank 8	1.2	0.5	0.0	0.4	0.1	0.0
Bank 9	3.8	0.1	0.0	0.2	0.2	0.0
Bank 10	0.4	0.2	0.2	0.5	0.1	0.7
Bank 11	0.0	4.7	0.0	0.0	0.1	0.0
Bank 12	4.3	1.9	2.2	0.2	0.1	0.1
Bank 13	0.4	0.0	0.0	0.5	0.0	0.0
Bank 14	0.0	1.3	0.0	0.0	0.1	0.0
Bank 15	3.5	0.5	0.4	0.7	1.0	0.6
Bank 16	0.0	0.1	0.0	0.0	2.9	0.1
Bank 17	0.2	0.1	0.0	2.8	5.8	0.0
Bank 18	0.7	0.3	0.3	1.2	0.5	0.2
Bank 19	0.4	0.4	0.4	2.4	0.7	0.1
Bank 20	0.2	0.1	0.1	0.5	0.2	0.1
Bank 21	6.5	2.9	3.3	0.2	0.1	0.1
Bank 22	0.0	0.0	0.0	0.0	0.0	0.0
Bank 23	5.1	2.3	0.0	0.2	0.2	0.0
Bank 24	0.6	0.3	0.0	0.2	0.1	0.0
Bank 25	6.0	2.6	2.9	0.2	0.1	0.1

Source: SBIF and author’s calculations.

In January 2009, Bank 3 accounted for 6.7 percent of the total capital in the banking system. In the hypothetical case that a credit shock affecting Bank 3 realizes, the banking system may suffer a capital loss of 7.9 percent, of which 6.7 percent corresponding to the capital of Bank 3 capital and an excess capital loss of 1.2 percent from banks with exposure to Bank 3. Hence, it can be stated that the TCTF risk posed by Bank 3 is equivalent to 1.2 percent of the banking system capital. As of December 2009, excess capital losses are relatively small and at most equal to 1½ percent for shocks from Bank 4. The overall analysis indicates that TCTF risk in the domestic banking system in Chile is relatively small.

Table 7. Banking system excess capital loss, in percent

The table shows banking system excess capital losses, in percent of capital in the banking system, induced by the failure of one bank. Excess capital losses are the total banking losses excluding the losses from the bank that triggered subsequent shocks in the system.

	Type of shock								
Banking system exces capital loss	Credit shock			Funding shock			Credit and funding shock		
due to shocks from:	Jan. 2009	Jul. 2009	Dec. 2009	Jan. 2009	Jul. 2009	Dec. 2009	Jan. 2009	Jul. 2009	Dec. 2009
Bank 1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Bank 2	0.7	0.0	0.1	0.0	0.0	0.0	0.7	0.0	0.1
Bank 3	1.2	0.2	0.7	0.0	0.0	0.0	1.2	0.2	0.7
Bank 4	0.1	0.5	6.9	0.2	0.0	0.0	0.2	0.5	6.9
Bank 5	1.8	0.2	1.0	0.0	0.1	0.1	1.8	0.2	1.1
Bank 6	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Bank 7	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Bank 8	0.0	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.0
Bank 9	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0
Bank 10	0.0	0.0	0.7	0.2	0.1	0.1	0.2	0.1	0.7
Bank 11	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
Bank 12	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Bank 13	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Bank 14	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
Bank 15	0.1	0.1	0.6	0.2	0.0	0.0	0.2	0.1	0.6
Bank 16	0.0	0.4	0.0	0.0	0.1	0.1	0.0	0.5	0.1
Bank 17	0.4	0.9	0.0	0.2	0.0	0.0	0.6	0.9	0.0
Bank 18	0.1	0.0	0.1	0.2	0.1	0.1	0.3	0.1	0.2
Bank 19	0.4	0.1	0.0	0.0	0.1	0.1	0.4	0.1	0.1
Bank 20	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Bank 21	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1
Bank 22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bank 23	0.0	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.0
Bank 24	0.0	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.0
Bank 25	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.1	0.1

Source: SBIF and author's calculations.

IV. CONCLUSIONS

Interconnectedness risk and the externalities associated with Too-Connected-to-Fail institutions have been a major amplifying and transmission mechanism during the 2008/9 global financial crisis. In response, there have been renewed efforts to understand and measure interconnectedness and TCTF risk and to ensure that the risk is properly addressed, as advanced in the current proposals for reforming the regulatory and supervisory framework as suggested in BCBS (2010) and Brunnermeier et al (2010). For instance, recent proposals on capital charges on interconnectedness risk are described in Adrian and Brunnermeier (2009), Chan-Lau (2009c), Gauthier, Lehar, and Souissi (2009), and Tarashev, Borio, and Tsatsaronis (2009).

This paper has illustrated the use of a simple methodology, balance sheet-based network analysis, to capture interconnectedness and TCTF risk in domestic and international banking systems using publicly available data sources under extreme adverse scenarios. In contrast to graph theory-based network analysis, there is no complex mathematics involved in the analysis but just simple balance sheet accounting identities. In consequence, balance sheet-based network analysis can be easily implemented whenever balance sheet data is available.

In the case of the global banking system, the analysis relies on data on cross-country claims compiled by the BIS. The results point out that shocks affecting the solvency of banks based in the UK and US, and to a lesser extent, in Germany, could be the main sources of risk to banking systems worldwide. The results, however, should be interpreted with caution due to the high level of aggregation of the data.

In the case of Chile, detailed data at the bank level on claims and liabilities vis-à-vis other banks in the system, foreign banks, and non-bank financial institutions are available from the banking supervisory agency. The results suggest that TCTF risk is low and that, from a financial stability perspective, financial surveillance is better focused on the linkages of domestic banks with foreign banks and non-bank financial institutions.

Finally, while there are advantages to the use of balance sheet data and accounting identities there are also some disadvantages related to the reliability of accounting data, as it is subject to manipulation, and the reporting lags, which may render the analysis irrelevant, especially if interbank exposures are changing rapidly[14]. Some of the disadvantages can be addressed by complementing network analysis with market-based measures, which use information from security prices and common economic factors to assess TCTF risk. Examples of recent work in this direction are Adrian and Brunnermeier (2009), Chan-Lau (2009b), and Chan-Lau et al (2009) among others.[15]

[14] Even sophisticated financial institutions may have problems collecting accounting data on a timely basis. According to Paul Friedman, COO of fixed income at Bear Stearns in 2008: “We go through the cash position, and there’s lot of questions as to how accurate it is…The firm was not really set up –most firms are not- to do real-time cash accounting,” as quoted in Hagan (2009).

[15]One caveat about using security prices, however, is that prices may not fully reflect the fundamental value of the banks and/or their true default risk: prices may be capturing the effects of factors like liquidity and technical supply and demand drivers, such as regulatory changes, that affect the decisions of market participants.

APPENDIX I. GRAPH THEORY-BASED NETWORK MODELS

Graph theory is the natural analytical framework for analyzing the properties of a financial system once it has been mapped into a digraph. In particular, it is possible to classify the different banks (vertices) into clusters and to evaluate how the system changes after the removal of a set of banks (vertices) and their respective linkages (arcs). In the latter case, the use of random graph theory makes possible to add randomness either to the number of banks (vertices) in the system (digraph) or to the existence of linkages (arcs) between them. Random graph theory can, in principle, accommodate the observation that the number of participants in a connected financial system as well as the nature of their cross-linkages change over time

Graph theory has been used extensively to analyze payment and settlement systems, as in Somaraki et al (2007), Bech, Chapman and Garrat (2008), and Embree and Roberts (2009) among others. The focus of the analysis has been mostly on the topological properties of the system. Some of the topological properties include size, or the number of institutions in the system, connectivity, or the relative number of existing linkages to the maximum number of linkages, and the clustering coefficient, or the probability that two institutions "close" to a third one are also "close" to each other.

The insights gained from the application of graph theory to payment and settlement systems are difficult to translate to more complex systems, such as the interbank market, a domestic banking system, or the global financial system. The difficulty arises from the relatively complexity that characterizes cross-claims across financial institutions, which stand in sharp contrast with the homogeneity of the transactions undertaken in the payment and settlement systems. Notwithstanding this difficulty, there have been some recent advances in extending graph theory to the analysis of complex banking systems in stylized models. Hattori and Suda (2007) use BIS banking data to analyze the topological properties of cross-border banking networks and their implications for banking stability. Nier et al (2007) use Erndos-Renyi graphs to explore how the different topological properties of a banking system affect the propagation of defaults. Gai and Kapadia (2009) model use the small-world model of Watts (2002) to analyze contagion in a stylized network using numerical simulations.

Calibrating graph theory-based models with real data remains a major challenge for bringing these models to an operational level suitable for surveillance and supervisory purposes. As an alternative, applied research in policy making institutions has opted for a simpler approach based on balance sheet data which is described in the main text.

REFERENCES

Acharya, V.V., and T. Yorulmazer, 2007, "Too Many to Fail – An Analysis of Time-Inconsistency in Bank Closure Policies," Bank of England Working Paper No. 319.

Adrian, T., and M. Brunnermeier, 2009, "CoVaR," mimeo (New York: Federal Reserve Bank).

Ahuja, R., T.L. Magnanti, and J.B. Orlin, 1993, *Network Flows: Theory, Algorithms, and Applications* (New York: Prentice Hall).

Aikman, D., P. Alessandri, B. Eklund, P. Gai, S. Kapadia, E. Martin, N. Mora, G. Sterne, and M. Willison, 2009, "Funding Liquidity Risk in a Quantitative Model of Systemic Stability," mimeo (London: Bank of England).

Bank for International Settlements, 2008, *Guidelines to the International Consolidated Banking Statistics* (Basle).

Bank for International Settlements, the Financial Stability Board, and International Monetary Fund, 2009a, *Guidance to Assess the Systemic Importance of Financial Institutions, Markets and Instruments: Initial Considerations* (Basel).

_____, 2009b, *Guidance to Assess the Systemic Importance of Financial Institutions, Markets and Instruments: Initial Considerations – Background Papers* (Basel).

Financial Stability Board and International Monetary Fund, 2009, *The Financial Crisis and Information Gaps* (Basle).

Basel Committee on Banking Supervision, 2010, *Strengthening the Resilience of the Banking Sector*, Consultative Document (Basle).

Bech, M., J. Chapman, and R. Garratt, 2008, "Which Bank is the 'Central' Bank? An Application of Markov Theory to the Canadian Large Value Transfer System," Working Paper No. 2008-42 (Ottawa: Bank of Canada).

Bollobas, B., 1998, *Modern Graph Theory* (New York: Springer).

Brunnermeier, M., A. Crockett, C. Goodhart, A. Persaud, and H. Shin, 2009, "The Fundamental Principles of Financial Regulation," *Geneva Reports on the World Economy* 11 (Geneva).

Chan-Lau, J.A., 2009a, "The Global Financial Crisis and its Impact on the Chilean Banking System," mimeo (Washington, DC: IMF)

_____, 2009b, "Risk Codependence in the Global Financial System," in G. Gregoriou, editor, *The Banking Crisis Handbook* (New York: CRC Press, Taylor & Francis Group).

_____, 2009c, "Regulatory Capital for Too-Connected-To-Fail Institutions: A Practical Proposal," forthcoming in *Financial Markets, Institutions and Instruments*.

_____, 2010, *Systemic Risk Measurement and Surveillance: Practical Tools and Excel-Based Implementation for Market Analysts and Financial Supervisors*, book in progress.

Chan-Lau, J.A., M. Espinosa, K. Giesecke, and J. Solé*,* 2009, "Assessing the Systemic Impliations of Financial Linkages," Chapter 2 in *Global Financial Stability Report*, April (IMF).

Durrett, R., 2007, *Random Graph Dynamics* (New York: Cambridge University Press).

Elsinger, H., A. Lehar, and M. Summer, 2006, "Risk Assessment for Banking Systems," *Management Science*, Vol. 52, No. 9, pp. 1301–66.

Embree, L., and T. Roberts, 2009, "Network Analysis and Canada's Large Value Transfer System," Discussion Paper No. 2009-13 (Ottawa: Bank of Canada).

Furfine, C., 2003, "Interbank Exposures: Quantifying the Risk of Contagion," *Journal of Money, Credit and Banking*, Vol. 35, No. 1, pp. 111–28.

Gai, P., and S. Kapadia, 2009, "A Network Model of Super-Systemic Crises," Working Paper No. 542 (Santiago: Banco Central de Chile).

Gauthier, C., A. Lehar, and M. Souissi, 2009, "Macroprudential capital requirements and systemic risk," working paper (Ottawa: Bank of Canada).

Hagan, W.D., 2009, *House of Cards: A Tale of Hubris and Wretched Excess on Wall Street* (New York: Doubleday).

Hattori, M., and Y. Suda, 2007, "Developments in a Cross-Border Bank Exposure Network," in Committee on the Global Financial System, *Research on Global Financial Stability: the use of BIS International Financial Statistics* (Basle: BIS).

Van Lelyvled, I. and F. Liedorp, 2006, "Interbank Contagion in the Dutch Banking Sector: A Sensitivity Analysis," *International Jounral of Central Banking*.

Markose, S., S. Giansante, M. Gatkowski, and A. Shaghaghi, 2009, "Too Interconnected to Fail: Financial Networks of CDS and Other Credit Enhancement Obligations of U.S.

Banks," mimeo, Centre for Computational Finance and Economic Agents, University of Essex.

Nagurney, A., and S. Siokos, 1997, *Financial Networks – Statics and Dynamics* (Heidelberg: Springer).

Nier, E., J.Yang, T. Yorulmazer, and A. Alentorn, 2007, "Network Models and Financial Stability," *Journal of Economic Dynamics and Control*, Vol. 31, No. 1, pp. 2033–60.

Sheldon, G., and M. Maurer, 1998, "Interbank Lending and Systemic Risk: An Empirical Analysis for Switzerland," *Swiss Journal of Economics and Statistics*, Vol. 134, pp. 685-704.

Soramaki, K., M.L. Bech, J. Arnold, R.J. Glass, and W.E. Beyeler, 2007, "The Topology of Interbank Payment Flows," *Physica A*, Vol. 379, pp. 317–33.

Tarashev, N., C. Borio, and K. Tsatsaronis, 2009, "The Systemic Importance of Financial Institutions," *BIS Quarterly Review*, pp. 75–87 (September).

Upper, C., and A. Worms, 2004, "Estimating Bilateral Exposures in the German Interbank Market: Is there a Danger of Contagion?" *European Economic Review*,

Watts, D., 2002, "A Simple Model of Global Cascades on Random Networks," *Proceedings of the National Academy of Sciences*, Vol. 99, pp. 5766 – 71.

Wells, S., 2004, "Financial Interlinkages in the U.K. Interbank Market and the Risk of Contagion," Working Paper No. 230 (Bank of England).