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Funding Shocks through Cross-border Banking in Asia A Network-based Approach

Estelle Xue Liu, IMF
Zijun Liu, HKMA

香港城市大學
City University of Hong Kong
專業 創新 胸懷全球
Professional · Creative For The World
城大商學院
College of Business
CITY UNIVERSITY OF HONG KONG
Department of ECONOMICS & FINANCE

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A Network-based Approach[1]

Prepared by Estelle Xue Liu and Zijun Liu

The views expressed in this paper are those of the authors, and should not be reported as representing the views of the Hong Kong Monetary Authority (HKMA) and the International Monetary Fund (IMF).

Abstract

In recognition of the potential risk arising from the rapidly increasing cross-border interbank funding in Asia, we examine the contagion of funding shocks through the regional interbank network. We find that the breadth and the final impact of the shock crucially hinge on the magnitude of the shock, initial liquidity buffers and the structure of the interbank network. Liquidity hoarding during financial distress aggravates the severity of the shock, while the interconnectedness of the interbank network may either aggravagate or mitigate the shock depending on the size of the shock.

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Keyword: funding runs, interbank, network analysis, financial crisis, liquidty ratio, Asia.

1 Contact Information: Estelle Xue Liu (corresponding author), International Monetary Fund, eliu@imf.org; Zijun Liu, Monetary Management Department, HKMA, zliu@hkma.gov.hk.

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I. Introduction

Two decades after the Asian Financial crisis, external liabilities of Asian banks are once again on the rise. During 1998-2007, total cross-border interbank liabilities of major Asian economies stayed almost unchanged in nominal values. But in the following decade, this value more than doubled to around 3.4 trn USD at the end of 2017. [2] These cross-border interbank liabilities are mostly denominated in third party currencies, more than half of which are in US dollars (USD).[3]

This recent development is not surprising in consideration of two facts. First, in the last decade, Asian economies are increasingly interlinked through trade and investment, prompting rapid growth in cross-border transactions by Asian banks. Second, the US dollar (USD) is often the currency of choice for international trade, cross-border bank lending and international debt issuance.

In light of the recent development, questions arise. Have Asian banks become more vulnerable to external shocks as a result of the increase in cross-border interbank liabilities? What types of external shocks could unsettle the banking sector at large in Asia? Which economies are the most vulnerable to these external shocks? Do increasing linkages among banks in the region mitigate or amplify the impact of these external shocks? What policy instruments could help enhance the resilience of the banking system?

Historical experiences repeatedly highlight the vulnerability of banks to foreign currency (FX) funding shocks and the role of the interbank network in amplifying the initial seemingly harmless shocks. The network of cross-border liabilities creates channels through which a funding shock can spread from one economy to another. A severe contagion of funding shocks could eventually disrupt the provision of credit to households and businesses across economies in the network, causing recessions. For example, during the Asian financial crisis, international banks' decision to deleverage and thus not to roll over short-term foreign currency loans has been a cause of financial crises in many Asian economies.

To enhance banks' resilience to funding shocks, regulatory rules have progressed in recent years. Since the global financial crisis, new liquidity rules are put in place in Basel III to ensure that banks have sufficient liquidity buffer during the period of financial stress, including the Liquidity Coverage Ratio (LCR) requirement of 100%. [4] Most Asian economies have already imposed regulatory minimum requirement for LCRs on an all-currency basis. Yet, it is not a common practice to impose LCR requirements on USD and other foreign currencies.

2Major Asian economies include Australia, China, Chinese Taipei, HK SAR, Indonesia, Japan, Malaysia, New Zealand, Philippines, Singapore, South Korea, and Thailand.
3 Based on published BIS database, USD denominated liabilities are only available for liabilities of all sectors, including both bank and non-bank sectors. We use the share of USD denominated liabilities of all sectors as a proxy for USD denominated liability of the banking sector, and reached the conclusion that more than half of interbank liabilities are denominated in US dollars.
4 See BIS (2013).

In this paper, we assess the funding risk of the cross-border interbank network in Asia. For this purpose, we construct a network of cross-border interbank claims and liabilities, and simulate the transmission of funding shocks through this network.

We adopt the network analysis approach and conduct our studies in two steps.

In the first step, we construct a matrix of cross-border interbank claims of 12 Asian economies (Asia-12) plus four major advanced economies outside of Asia (AE-4). Asia-12 include Australia (AU), mainland China (CN), Hong Kong (HK), Indonesia (ID), Japan (JP), South Korea(KR), Malaysia (MY), New Zealand (NZ), Philippines (PH), Singapore (SG), Taiwan (TW) and Thailand (TH). Advanced economies from outside of the region (AE-4) include Euro area economies (EA), Switzerland (CH), the United Kingdom (UK) and the United States (US), whose banks interact actively with banks located in Asia, either directly or through their regional branches or subsidiaries. As we use country level data, the banking system of each economy is considered as one single 'bank' in the network. This matrix allows us to see beyond the immediate point of impact and identify potential sources of contagion and pressure points.

In the second step, we design a simulation framework for the transmission of funding shocks. The shock transmission mechanism could be established as follows. Initially, we impose an exogenous shock on the cross-border interbank lending to Asia-12 from AE-4. When facing a funding cut, a bank would first draw down its excess liquidity buffer. If the buffer is insufficient, the bank would cut lending to other banks. As a last resort, if both the liquidity buffer and interbank credit cut are insufficient to cope with the shock, the bank would need to liquidate its other assets. This last measure could lead to either a fire sale of assets or a reduction in credit provision, eventually disrupting the real economy. Therefore, we define the use of the last measure as a distress event. The final impact of a funding shock is measured by the total amount of other assets (assets other than liquidity buffers and interbank credit) the bank has to liquidate.

A driver of shock amplification in the simulation framework is the liquidity hoarding behavior during stress. According to the Basel Committee, banks are expected to use its liquidity buffer during a period of stress (BIS, 2013). However, there is plenty of evidence from the literature that banks have incentives to hoard liquidity, i.e. hold more liquidity buffer than necessary, during stress (Acharya and Merrouche, 2010). This means that even if a bank does not have liquidity problems itself, it might transmit liquidity shocks to other banks by withdrawing from interbank markets and hoarding liquidity.

Unfortunately, data on foreign currency liquidity ratios of Asia-12 are not publicly available, and therefore we are not able to quantitatively assess the current level of interbank funding contagion risk in Asia. Instead, we run the simulation model based on different assumptions of the liquidity ratio and identify key contagion drivers. Using this simulation framework, we experiment with different sizes of shocks, initial liquidity ratios and the behavior of liquidity hoarding in the network. In addition, we test whether a more interconnected network enhances or reduces resilience of the network to funding shocks.

Our main findings are as follows. First, economies with net cross-border interbank liabilities tend to be more vulnerable, but sufficient liquidity buffer could enhance the resilience of the banking system in face of shocks. Higher level of liquidity buffers is desirable for economies more susceptible to large funding shocks. In addition, economies that have large interbank claims are more likely to transmit shocks to other economies. Japan, as one of the major borrowers from AE-4 and core credit suppliers to the region, is the most important node in the network in transmitting a funding shock. Hong Kong and Singapore are less systematically important, as Hong Kong is in fact a net creditor to AE-4 while Singapore's net claims on regional banks are small relative to Hong Kong and Japan.

Finally, our results show that greater interconnectedness may not always be beneficial in the presence of liquidity hoarding behavior. When shocks are sufficiently severe, a higher degree of interconnectedness could increase the probability of a distress event, and make the interbank network more vulnerable to funding shocks.

Section II gives a summary of related literature, and section III discusses data and the current interbank network in Asia. Section IV describes the simulation approach and discusses the results. Section V concludes.

II. Literature review: Network Analysis for Liquidity Shocks

There is an extensive academic literature on the transmission of funding shocks through the interbank network. The seminal work of Allen and Gale (2000) concluded that a small liquidity shock can spread by contagion throughout the economy when the interbank market is incomplete. An interbank market is "complete" if each region is connected to all other regions, and is "incomplete" if each region is connected with a small number of other regions. They argued that if the interbank market is complete, when facing with a global shortage of liquidity, every region will take a small hit by liquidating a small amount of the long asset, thus there may be no need for a global crisis. With incomplete markets, banks in the troubled region have a direct claim only on the banks in adjacent regions, while the banks in other regions pursue their own interests and refuse to liquidate the long asset until they find themselves on the front line of the contagion.

Another example is Freixas, Parigi and Rochet (FPR, 2000), which also studies financial contagion in the interbank market. Closely related to Allen and Gale (2000), the model of FPR (2000) is driven by the movement of depositors from one region to another, rather than by exogenous liquidity shocks. [5] In this model, interbank credit allows banks

[5] This model builds on the Diamond-Dybvig (1983), but sets parameters so that no depositors would need to withdraw their deposits from a solvent bank before the final date.

to avoid costly liquidation in meeting early withdrawals, but also becomes a channel of contagion. In particular, FPR (2000) contrast two network topologies: a ring network and a completely connected network. Different from Allen and Gale (2000), they show that a ring network is more resilient to a bank run as an insolvent bank can pass a greater fraction of its losses to other banks.

A different approach is exemplified by the framework of Gai, Haldane, and Kapadia (GHK, 2011), which investigates the transmission of liquidity shocks in a richer variety of network structure. GHK (2011) estimate the probability that at least 10 percent of banks will need to withdraw funding from other banks and, conditional on reaching this threshold, the fraction of banks affected. They experiment with different degrees of network interconnectedness, and point out that the probability of a systemic contagion is non-monotonic in interconnectedness, at first increasing before falling. However, the severity of a crisis, conditional on the occurrence of a crisis, consistently increases with interconnectedness.

In GHK (2011)'s model, liquidity hoarding and collateral haircut are two important basis for shock amplification. GHK (2011) observed that in a crisis-notably in the most recent one - banks respond to shocks by hoarding liquidity, meaning that they reduce their lending more than they need to in order to cover their own funding shortfall. In particular, banks may view an initial shock as a warning of greater scarcity to come and, as a precaution, increase their buffer of liquid assets by reducing their lending.

Acemoglu et al (2015), having studied the network's role as a shock propagation and amplification mechanism, argued that the extent of financial contagion relies on the magnitude of negative shocks. They pointed out that if a negative shock is sufficiently small, a more densely connected financial network, related to a more diversified pattern of interbank liabilities, is more stable; however, beyond a certain point, dense interconnections serve as a mechanism for shock propagation, leading to a more fragile system.

There are also a number of empirical studies on interbank liquidity shocks using a network approach. For example, Furfine (2003) quantifies contagion risk in the US banking system using unique data on interbank payment flows in the US federal funds market. The author finds that the potential for a liquidity contagion is greater than that for a solvency contagion. Ferrara et al (2017) estimates the systemic liquidity risk in the UK interbank system using a regulatory dataset on bilateral interbank claims. The authors find that a number of banks are 'systemically important' in the interbank funding network, i.e. the failure of these banks is more likely to spread contagion to other banks.

Despite a growing literature studying bank-level bilateral exposures, there is rarely a special reference to Asia. For example, Hale, Kapan and Minoiu (2016) are the first in building a global interbank network from granular, loan-level data and to examine the transmission of financial crisis through this network. Although bank-level data are preferable, individual bank exposure data in the Asian region are largely unavailable.

III. Interbank network in Asia

A. Data

Quantifying the complexity of interbank network is difficult, and data limitation is the biggest hurdle. Nevertheless, data on cross-border bank lending from Bank for International Settlements (BIS) allow us to construct an interbank network at country level.

BIS compiles two sets of bilateral banking statistics: locational (LBS) and consolidated (CBS) banking statistics. Both data sets are at country level, and the major difference between the two data sets lies in the treatment of claims and liabilities of non-resident international banks.

- **LBS** Similar to the principle of balance of payment statistics, the LBS measures cross-border banking activities from a residence perspective. Based on LBS, cross-border claims and liabilities include intra-group positions between offices of the same banking group located in different economies.
- **CBS** The CBS measures cross-border banking activities from a nationality perspective, focusing on the country where the banking group's parent is headquartered. The CBS excludes intragroup positions, similar to the consolidation approach followed by banking supervisors. The CBS provides two different measures of banking groups' country risk exposures, on either an immediate counterparty or an ultimate risk basis.

LBS measures cross-border activities better by including the intragroup activities. In practice, cross-border intragroup lending is not immune to external shocks. On the contrary, they could be more susceptible to external development. For example, in Hong Kong, branches of international banks are generally funded by overseas offices, including their headquarters, so their loans could be sensitive to external funding conditions, particularly in the home country and the US.[6] Kwan et al (2015) find that global banks use their foreign branches in Hong Kong as a funding source during a liquidity crunch in the home country.

CBS, on the other hand, offers important information on lending of international branches in host economies. It is likely that, during a liquidity crunch, foreign branches of banks in the crisis countries could cut their lending significantly in these countries. The reduced lending activities by resident foreign branches are only reflected in CBS data.

[6] 44 of the top 50 global banking organizations had branch operations in Hong Kong at the end of 2013.

In this paper, cross-border interbank networks are constructed based on LBS. Data from LBS are more complete in both the time and country dimension, in comparison to CBS. In addition, CBS do not provide well-defined cross-border interbank claims and liabilities: the reporting banks are grouped by the location of headquarters, while the counterparty banks are grouped on a residency basis.

One potential criticism for using aggregate country level data is that it fails to account for the heterogeneity of the banking sector. Unfortunately, bank level data on cross-border bilateral claims are not publicly available for the 12 Asian economies in our sample.

B. Interbank Network in Asia

Based on BIS LBS data, we construct the network of cross-border interbank claims and liabilities among 16 economies—Asia-12 and AE-4. In Figure 1, each node represents one economy, with the sizes of the nodes proportional to the real GDP of each economy. The destination of the arrow is the recipient of interbank credit, and the thickness of the arrow is proportional to the US dollar value of bilateral interbank exposures between economies. Due to data limitation, bilateral claims among CN, ID, MY, NZ, SG and TH are not available, but the label 'Others' in the figure is expected to capture these missing claims.[7] In the case of ID, MY, SG and TH, bilateral banking claims and liabilities to each other likely account for the lion's share of their claims and liabilities to 'Others', due to large trade, investment and banking linkages among these economies. [8]

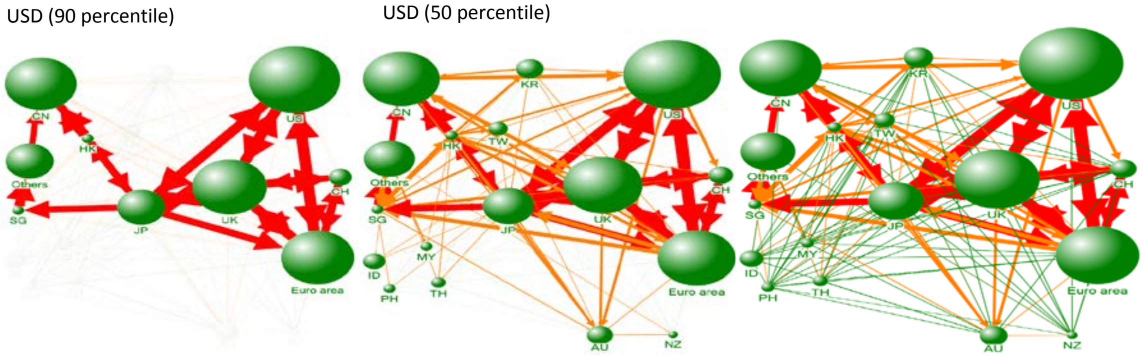
Figure 1. Cross-border Interbank Lending Network in Asia

(Q4 2017)

a. Cross-border inter-bank claims> 94 bn USD (90 percentile)

b. Cross-border inter-bank claims> 5.6bn USD (50 percentile)

c. All



Sources: BIS locational banking statistics, CEIC and HKMA staff.
Note: This figure shows bilateral interbank claims between 16 economies in our sample at the end of Q4 2017. Interbank claims are calculated as claims on all sectors minus claims on the nonbank sector. Also, for for banking claims that are not published by the BIS, mirror data are used. For example, China's liability to Hong Kong is calculated using Hong Kong's claims on China. The destination of the arrows indicates the country of destination of the banks

7 'others' is calculated as the residual claims that are not captured by any bilateral interbank linkages in Figure 1.
8 In general, Singaporean banks have large presence in ID, MY and TH.

holding the claims, while the arrow's thickness is proportional to the US dollar value of the claims. The size of the vertex is proportional to each economy's real GDP in USD terms.

Table 1. Cross-border Interbank Lending Network, Q4 2017 (bn USD)

Borrowers \ Lenders	AU	CN	TW	HK	ID	JP	KR	MY	NZ	PH	SG	TH	CH	EA	UK	US
AU	.	11	13	47	0	28	1	0	8	0	20	0	3	14	31	47
CN	29	.	54	256	.	35	38	.	.	.	.	.	2	50	55	19
TW	2	4	.	44	.	4	2	0	0	0	25	2	1	9	8	9
HK	18	140	25	.	.	126	10	2	1	4	77	6	22	62	42	32
ID	1	.	1	4	.	11	2	.	.	.	.	.	0	1	3	2
JP	9	19	17	122	1	.	7	1	0	1	63	2	3	90	215	167
KR	4	25	5	47	0	14	.	0	0	0	16	1	1	10	7	16
MY	0	.	2	6	.	3	0	.	.	.	.	.	0	1	3	2
NZ	15	.	0	3	.	1	0	.	.	.	.	.	0	0	3	1
PH	1	0	1	2	0	2	1	0	0	.	5	0	0	0	3	1
SG	22	.	13	82	.	127	5	.	.	.	.	.	19	84	66	43
TH	1	.	0	13	.	19	0	.	.	.	.	.	0	0	2	1
CH	1	2	3	10	0	6	0	0	0	1	11	0	.	125	167	54
EA	17	11	5	57	2	138	6	3	0	1	25	2	151	.	1073	268
UK	43	73	15	68	1	83	3	1	1	2	37	1	125	855	.	395
US	20	82	8	45	7	164	23	4	1	5	39	3	24	271	461	.

Sources: BIS locational banking statistics, CEIC and HKMA staff.
Note: Cross-border lending between 0.9 bn USD (25 percentile) and 5.6 bn USD (median) are highlighted in yellow, between 5.6 bn USD (median) and 94 bn USD (90th percentile) are highlighted in orange, while larger than 94 bn USD are highlighted in red.

Underlying data for Figure 1 (Table 1) show that cross-border interbank claims from within and outside of Asia are both important. Overall, Asia-12 receives around 1.7 trn USD total credit from the Asia-12 network, versus 1.2 trn USD from AE-4. Asian banks are on average net borrowers from the AE-4, although gross flows in each direction remain considerable. Consistent with Remolona and Shim (2015), we find that banking credit from within Asia has outpaced that from outside of the region in recent years. In particular, the share of credit from European banks has declined.

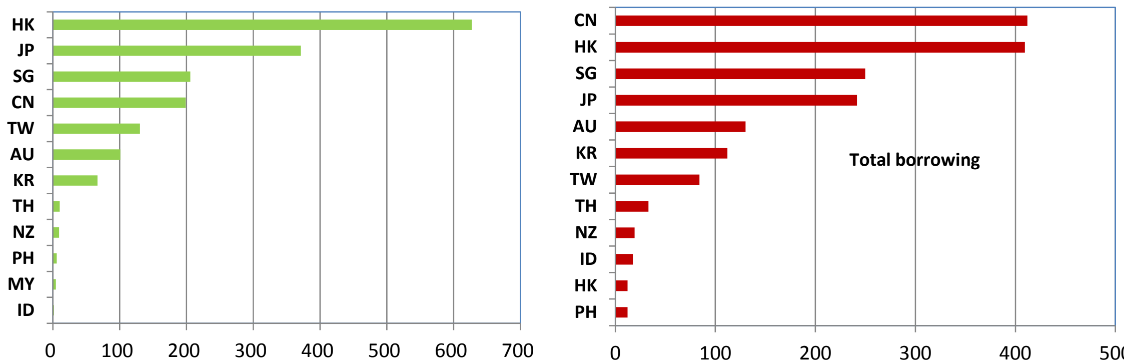
Concentration in the network is clearly visible in Figure 1, with a few core advanced economies and regional financial centres dominating the web of linkages. JP has the largest exposure to AE-4, while HK and SG both have direct large exposures to EA and indirect exposures through Japan. Figure 2 ranks the 12 Asian economies based on the total lending and borrowing from other economies in the Asia-12 network, further confirming the role of HK, SG, CN and JP as core economies in the network. Although CN also ranks high, its cross-border activities are mainly conducted with HK. [9] At 2017Q4,

[9] China might further extend its lending to other economies in the network through. However, as money is fungible, we would not able to prove the role of HK as an intermediary for Chinese credit in the network. If we rank economies by their median bilateral lending and borrowing, use the median bilateral lending and borrowing, Hong Kong is the largest borrower and lender, followed by Singapore. Japan ranked number three, but its median lending and borrowing are significantly lower than

around 69 percent of cross-border interbank credit from the Asia-12 originated from JP, HK and SG.

Figure 2. Total cross-border interbank lending to and borrowing from Asia-12

(bn USD, 2017Q4)



Sources: BIS Locational Banking Statistics, and HKMA staff.

Cross-border bank liabilities are mostly denominated in third party currencies, US dollar in particular. US dollar denominated bank lending accounts for a large portion of total cross-border lending by Asian banks.[10] On average, 54 percent of cross-border liabilities of Asia-12 to international banks were denominated in USD at the end of 2017. This is not surprising, as international banks play a central role in the global US dollar system through both lending and derivative market activities. Overall, non-US banks' US dollar balance sheets rely more on short-term wholesale dollar funding than do their consolidated balance sheets, which has been highlighted by the IMF as a potential source of risk.[11]

The banking system in Asia is also increasingly interconnected. Between 2006 Q4 and 2017 Q4, Asian banks' borrowing from the network of Asia-12 as a share of total borrowing increased from 17 to 27 percent.[12] CN is one of the exceptions, however, as the economy so far has not borrowed extensively from outside of the region.

IV. Simulations of Funding Shocks

A. Simulation Framework

In this section, we lay out a simulation framework to explore the resilience of the interbank network of Asia-12 to funding shocks originating from AE-4.

Hong Kong and Singapore, while and Singapore remain the largest lenders and borrowers, while China's median lending and borrowing are even much lower.

10 Unfortunately, USD bilateral interbank lending is not publicly available. We therefore use USD cross border bank lending to all sectors as a proxy.

11 See IMF (2018) for more detailed discussion.

12 Values do not include borrowing from Hong Kong, as Hong Kong only started reporting data from Q4, 2014.

Representative bank and cross-border interbank network

The interbank network, as presented in Figure 1, consists of 12 Asian economies and four advanced economies outside of Asia. These economies are linked with each other by bilateral interbank positions. These bilateral interbank positions are based on country level data, which could be interpreted as there is one representative bank in each economy. In this setting, the 12 Asia economies are equivalent to 12 banks, and interbank activities are equivalent to cross-border activities. We denote each of the 12 Asia economies by i, where $i = 1 \dots 12$.

Table 2 presents a stylized balance sheet of a representative bank. This bank has three categories of assets—high quality liquid assets, interbank loans and other assets, denoted by B_i, C_i and O_i respectively. Other assets are claims on non-bank entities, both domestic and foreign, such as loans and securities. We assume that all interbank loans are short-term (i.e. can be withdrawn within the duration of the stress period) and unsecured.[13] The bank's liabilities include equity, interbank borrowings and obligations to nonfinancial entities, such as deposits.

Table 2. A stylized balance sheet for a representative bank in the network.

Assets	Liabilities
High quality liquid assets (B_i)**:** e.g. cash, central bank reserves, high-quality government bonds.	**Interbank borrowings:** short-term and unsecured
Interbank loans (C_i): short-term and unsecured	**Liabilities to non-bank entities**: e.g. deposits
Other assets (O_i) : e.g. loans and securities	**Equity**

Cross-border interbank liabilities

In our simulation, the vulnerability of a bank depends on the size of its interbank liabilities to other bank in the network. We denote the liability of bank i to bank j by $M(i,j)$, for $i,j = 1 \dots 12$, where M is the matrix of cross-border interbank liabilities. In addition, we denote the net liabilities of each Asia-12 economy to AE-4 by N_i, for $i = 1 \dots 12$.

While cross-border interbank positions are mostly denominated in third-party currencies, there are exceptions. For example, some of China's claims on Hong Kong are denominated in Chinese Yuan, and some bilateral interbank positions with Japan are denominated in Japanese yen. Because the currency breakdown of bilateral cross-border claims is not publicly available, for simplicity, we assume that all cross-border claims and liabilities are denominated in non-Asian currencies.[14] As a robustness check,

13 Empirical evidence shows that the vast majority of interbank loans mature within three months (e.g. Kuo et al (2014) and Langfield et al (2014)), and that the cross-border repo market within Asia is very small (ASIFMA and ICMA (2017)).
14 Based on aggregate currency decomposition of cross-border bank lending to all sectors, provided by BIS, the majority of these positions are denominated in non-Asian currencies,

we also use confidential data on USD cross-border claims and liabilities and our results remain qualitatively the same.

Liquidity buffer

To mitigate potential short-term funding shocks, banks in the network hold a certain level of highly liquid FX-denominated assets.[15] Accordingly, each bank targets a FX liquidity ratio, which is defined, in a similar fashion to the LCR, as the ratio of FX-denominated liquid assets to short-term FX-denominated net funding outflows. We denote the FX LCR of each bank as R_i, where

$$R_i = \frac{B_i}{\max\left(\sum_j M(i,j) - \sum_j M(j,i) + N_i, 0\right)} \quad (1)$$

A FX liquidity ratio (R_i) of 100 percent means there would be funds available to cover all possible FX-denominated net outflows during the stress period. The duration of the stress period is not essential in our framework. As quarterly data are used, we assume that the stress period lasts for three months. Although the FX liquidity ratio defined in this paper is conceptually similar to the LCR, it is different from the LCR in a number of ways. For example, the LCR's denominator is net outflows over 30 days, versus three months in this paper. The LCR also includes outflows from deposits and off-balance sheet liabilities, which are excluded in our analysis due to data limitations.

In general, data on banks' FX liquidity ratios are not available, but the USD LCRs of banking systems in advanced economies, estimated by IMF (2018) could be useful references. At the end of 2017, the USD LCRs range between roughly 50 to 130 percent in advanced economies, according to IMF (2018). These ratios have increased significantly since the GFC. Before the GFC, for example, the LCRs for Germany and French banks were only around 10 percent, but now stood at above 50 percent.

There are no data available on FX LCRs in Asia except Japan, but most of these economies have established minimum requirements for all-currency LCRs. In Hong Kong, the average all currency LCRs of category 1 institutions was at 155 percent at 2017, well above the statutory minimum requirement of 80 percent applicable in 2017.[16] In Singapore, the regulatory requirement of all currency LCR is at 70 percent, and the average LCR of the local banking groups is well above this ratio at around 140 percent. [17] In South Korea, commercial banks' FX LCR, applied as a regulatory ratio beginning from 2017, was 105% at 2017Q3 (BOK, 2017). In other Asian economies, LCR requirements target liquidity denominated in either domestic currencies or significant foreign currencies, and mostly use 100 percent as the minimum ratio, to be achieved in the medium term. [18]

15 For simplicity, we assume all cross-border interbank claims or liabilities are denominated in FX.
16 See HKMA(2018), chapter 5.
17 See MAS (2017), chapter 2.
18 For example, both Malaysia and Philippines plan to adopt the minimum LCR regulatory requirement of 100% by 2019 (BNM 2015, BSP 2017). In Indonesia, no FX currency liquidity ratio is required. Instead, the banking system liquidity (local currency) is assessed using the ratio of liquid assets to non-core deposits (LA/NCD), which wasat 101 percent in 2017, above

Given the above data limitations, we are not able to quantitatively assess the current level of interbank funding contagion risk in Asia. Instead, we run the simulation model based on different assumptions of the liquidity ratio. In the baseline simulation, we assume a system-wide FX liquidity ratio at 50 percent (i.e. $R_{i,0} = 0.5$), the lower end of advanced economies' USD liquidity ratio at the end of 2017 (IMF, 2018). The reason for starting with an FX liquidity ratio lower than 100 percent is twofold. First, the 100 percent LCR ratio required by Basel III is to cover 30-day funding outflows, but in this paper we look at quarterly funding outflows. Second, the 100 percent LCR ratio is based on all currencies, but we focus more on the FX liquidity ratio. We also experiment with different liquidity ratios in our simulations.

Shock transmission

In our model, contagion arises when banks pull funding from one another. The contagion process is modelled using the classic Furfine (2003) methodology. We use $S_{i,t}$ to denote the funding shock on bank i, i.e. the amount of cross-border FX funding the bank needs to repay, in iteration t. We start with an initial exogenous shock (from AE-4), which reduces the net interbank funding to a bank in Asia-12. Specifically, for each bank i:

$$S_{i,0} = sN_{i,0} \tag{2}$$

where $N_{i,0}$ denotes the outstanding net funding borrowed from AE-4 by bank i at iteration 0, and s is a constant.

The initial magnitude of the funding shock is set at 70 percent in our baseline simulation, i.e. $s = 0.7$. The 70 percent is consistent with the magnitude of historical cross-border interbank funding shocks (at 50 percentile) to Asia-12. This funding shock could be due to higher global interest rates, or a global shortage of US dollar liquidity, or drop in confidence of an economy's asset quality. When its funding is reduced, a bank needs to liquidate its assets to continue serving its payment obligations.

We then introduce the pecking order for liquidating assets, in the similar fashion as laid out in Allen and Gale (2000). First, to cope with a shock at period t, the bank liquidates its liquidity buffer $B_{i,t}$, subject to the constraint that $B_{i,t}$ is greater than or equal to the target liquidity buffer $T_{i,t}$ (see the section below on liquidity hoarding for details). If the excess liquidity buffer $B_{i,t} - T_{i,t}$ is not enough to cover the funding shock, this bank will liquidate short-term interbank loans proportionally across all its borrowers. Finally, if the above is still not enough for the bank, it will liquidate other assets $O_{i,t}$.

The order is as such because by definition, the cost of obtaining liquidity by liquidating short-term asset used as liquidity buffer is minimal. Similarly, the cost of liquidating the remaining interbank short-term asset is slightly higher, but still below the cost of

its threshold of 50 percent (BI, 2017). The Bank of Thailand has also imposed the LCR framework on January 2016, with the minimum requirement beginning at 60 percent, rising in equal annual steps of 10 percentage points to reach 100% on January 2020 and thereafter.

liquidating other long-term assets which could result in capital loss as well as a reduction in income.[19] If the bank is not able to absorb the shock with its excess liquidity buffer, according to the pecking order, it withdraws its lending to other banks. Those banks will in turn need to reduce their lending, if they don't have enough liquidity buffers, further spreading the shock to other banks.

To summarize, the initial shock is transmitted through the following sequence:

1. At period t=0, banks suffer an initial shock $S_{i,t}$ on their net borrowing from AE-4;
2. At the same period and subsequently, where t=0, 1, 2, ..., banks liquidate their liquidity buffer, interbank loans[20] or other assets according to the pecking order;
3. At period t=1,2, 3,..., banks receive new shock $S_{i,t}$ on interbank loans from Asia-12, which is determined based on the amount of interbank loans liquidated, and banks update their target liquidity buffer $T_{i,t+1}$ based on the new shocks (see section below on liquidity hoarding for details);
4. The process repeats until there is no more liquidation of interbank loans.

Expressed in equations, given $S_{i,t}$ and $T_{i,t}$ at period *t, for t=0,1,2,3...*:

$$B_{i,t+1} = \max\left(B_{i,t} - S_{i,t}, T_{i,t+1}\right); \tag{3}$$

$$M_{t+1}(j,i) = M_t(j,i) \max\left[1 - \frac{S_{i,t} - \left(B_{i,t} - T_{i,t+1}\right)}{\sum_j M_t(j,i)}, 0\right] \tag{4}$$

for every j if $S_{i,t} > \left(B_{i,t} - T_{i,t+1}\right)$, and $M_{t+1}(j,i) = M_t(j,i)$ otherwise;

$$O_{i,t+1} = O_{i,t} - \left[S_{i,t} - \max\left(B_{i,t} - T_{i,t+1}, 0\right) - \sum_j M_t(j,i)\right] \tag{5}$$

if $S_{i,t} > \max\left(B_{i,t} - T_{i,t}, 0\right) + \sum_j M_t(j,i)$, and $O_{i,t+1} = O_{i,t}$ otherwise; and

$$S_{i,t+1} = \sum_j M_{t+1}(i,j) - \sum_j M_t(i,j) \tag{6}$$

for $t > 0$.

Liquidity hoarding

In our simulation, a key reason for shocks being amplified during a contagion is the behavior of liquidity hoarding, i.e. a bank may target a higher liquidity buffer T_i during the stress period.

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19 We assume that banks will not liquidate other assets purely to meet its target liquidity buffer.
20 Banks will not take into account the amount of interbank loans withdrawn by other banks until the next period.

Without liquidity hoarding, each bank will first cope with the funding shock with its own excess liquidity buffer, the amount of the interbank loans it needs to liquidate is always smaller than the initial shock. Following this argument, interconnectedness should always be beneficial as it diversifies and mitigates shocks.

However, in reality, if a bank faces or expects a liquidity shortage, it often hoards liquidity by withdrawing (or refusing to roll over) interbank loans. This means that even a bank has enough liquidity buffer to cope with its own funding shock, it might transmit liquidity shocks to other banks by hoarding liquidity, which could amplify the initial shock.

Empirical evidence (e.g. Heider, Hoerova and Holthausen (2015), Acharya and Merrouche (2010) and De Haan and Van den End (2013)) has shown that banks tend to hoard liquidity when the short-term funding markets are in stress. In particular, De Haan and Van den End (2013) and Van der Leij et al (2015) find that the amount of liquidity hoarding by banks increases in the size of negative funding shocks experienced. Consistent with this, in our simulation framework, we assume that the target liquidity ratio, i.e. the target liquidity buffer T_i over net funding outflows, is proportional to the cumulative loss of short-term funding experienced by bank i as a percentage of its initial interbank liabilities, i.e.

$$\frac{T_{i,t+1}}{\max\left(\sum_j M_t(i,j) - \sum_j M_t(j,i) + N_{i,t+1}, 0\right)} = \frac{\alpha \sum_{k=0}^{t} S_{i,k}}{\sum_{j,0} M(i,j) + N_{i,0}} \qquad (7)$$

where $T_{i,0} = 0$ and α is a constant. For example, if we set $\alpha = 1$ and 35% of a bank's interbank liabilities have been withdrawn, then the bank will target a 35% liquidity ratio. We assume $\alpha = 1$ in our baseline simulation, but also show results for different values of α.

Measurement of the systemic loss

Various measures have been proposed in the literature to measure the damage of a systemic event, but no consensus has been established regarding which measure is the best indicator. The proposed measures include: the number of banks that fail; the total loss of bank capital (see, for example, Cont, Moussa, and Santos, 2013); the cost of liquidating long-term assets to cover short-term liabilities; the aggregate loss inflicted on the nonfinancial sector, that is, the total shortfall in payments from the financial sector to households and non-financial firms; and the total loss in asset values summed over all entities in the system—the systemic loss in value.[21]

21 The systemic loss in value is the total amount by which the value of all claims-including interbank claims and claims by households and nonfinancial institutions on the financial sector are reduced relative to their nominal values. This measure counts credit losses for the real economy. Some studies have attempted to quantify these effects. See, among others, Gertler and Kyotaki (2010); Adrian and Boyarchenko (2012); Chen, Iyengar, and Moallemi (2013); Bassett et al. (2014); and Brunnermier and Sannikov (2014).

In our simulation, we use the total loss (L), defined as the total amount of 'other assets' that banks need to liquidate ($L = \sum_i \left(O_{i,0} - O_{i,k}\right)$, where k corresponds to the last iteration), to measure the final damage of a contagion. In addition, we define the event that at least one bank needs to sell its 'other asset' as a **distress event**.

Network properties

The structure of cross-border claims and obligations in the banking network plays a key role in determining how shocks spread thkuorough the network. Instead of assuming a network structure as in Allen and Gale (2000) or using random networks as in GHK (2011), we constructed the banking network using the actual bilateral interbank claims and liabilities, which is also the underlying data for Figure 1. Interbank claims among CN, ID, MY, NZ, SG and TH are not available, so we assume them to be zero in simulation. This could have over- or under- estimated these banks' net interbank liabilities. We discuss potential impact of this assumption on our results later in the discussion section.

We focus on the interconnectedness of the network, which can be interpreted as a measure of "regional" interconnectedness within Asia-12. In the network, Asian economies can either borrow directly from AE-4, or from other economies in Asia-12. All else equal, the more Asia-12 economies borrow via each other rather than directly from AE-4, the more interconnected the network becomes.

We define the degree of interconnectedness such that a value of zero corresponds to the network where no interbank claims exist within the network and all Asia-12 economies borrow directly from AE-4, and a value of one corresponds to the current network. The networks with degrees of interconnectedness less or greater than one are estimated using linear interpolation and extrapolation. For each economy in Asia-12, a higher degree of interconnectedness means more borrowing from Asia-12 and less direct borrowing from AE-4, but its total net liability stays unchanged. In our simulation, we only increase the degree of interconnectedness to 1.2 because otherwise some Asia-12 economies will have negative net borrowing from AE-4.

B. Simulations

We test five simulation models, the details of which are presented in Table 3. In the baseline model (model 1), we introduce a 70% exogenous funding cut by AE-4 on all economies in the network of Asia-12. The initial USD liquidity ratio is 50% for banks in the Asia-12 network. Model 2 experiments with various shock sizes and Model 3 tests different liquidity ratios and degrees of liquidity hoarding. In model 4, we introduce initial funding shocks on targeted economies only, and test which economies are more important in transmitting the shocks. Model 1-4 use the actual cross-border liabilities at 2017 Q4, as presented in Figure 2. To test the impact of the network structure in shock transmission, in model 5, we experiment different degrees of interconnectedness as described previously.

Table 3. Simulation Models

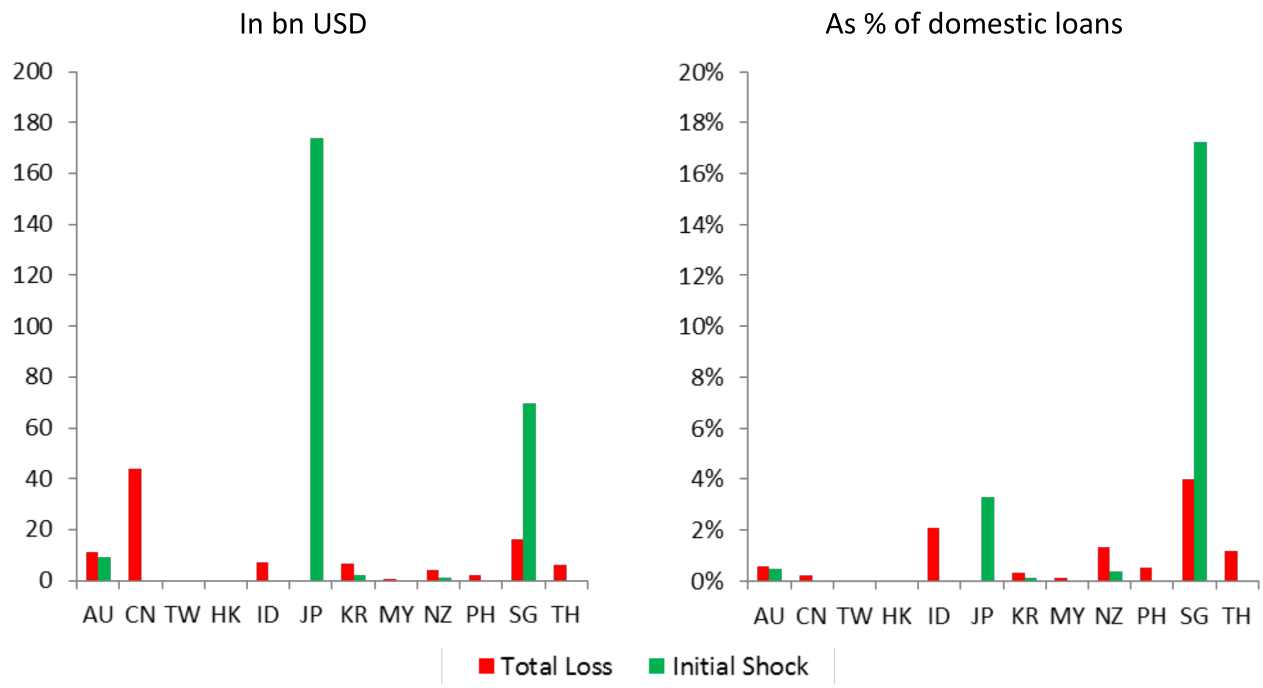
	Model 1 Baseline	Model 2 Shock size	Model 3 Liquidity ratios	Model 4. Targeted shock	Model 5. Interconnectedness
Matrix	2017Q4 Matrix	2017Q4 Matrix	2017Q4 Matrix	2017Q4 Matrix	Varying
Initial shock	70% on all Asia-12	70% on all Asia-12	Varying	80% on target economy	Varying
FX liquidity ratio	50%	50%	Varying	50%	50%
Liquidity hoarding	Yes	Yes	Varying	Yes	Yes

C. Results

Results from Model 1 are shown in Figure 3 and 4. Figure 3 presents the size of initial shock S (green column) and total loss L (red column) in the Asia-12 network, expressed both in nominal amounts and as a percentage of each economy's domestic loans to the non-financial sector. The latter measure is used in order to assess the importance of the shock to each individual country. As described in the previous section, the initial funding cut is 70% of each economy's net interbank liability to AE-4. Total loss, as defined earlier, is the total amount of 'other assets', lending to non-bank sectors, that banks need to liquidate. If total loss is larger than zero, the distress event occurs.

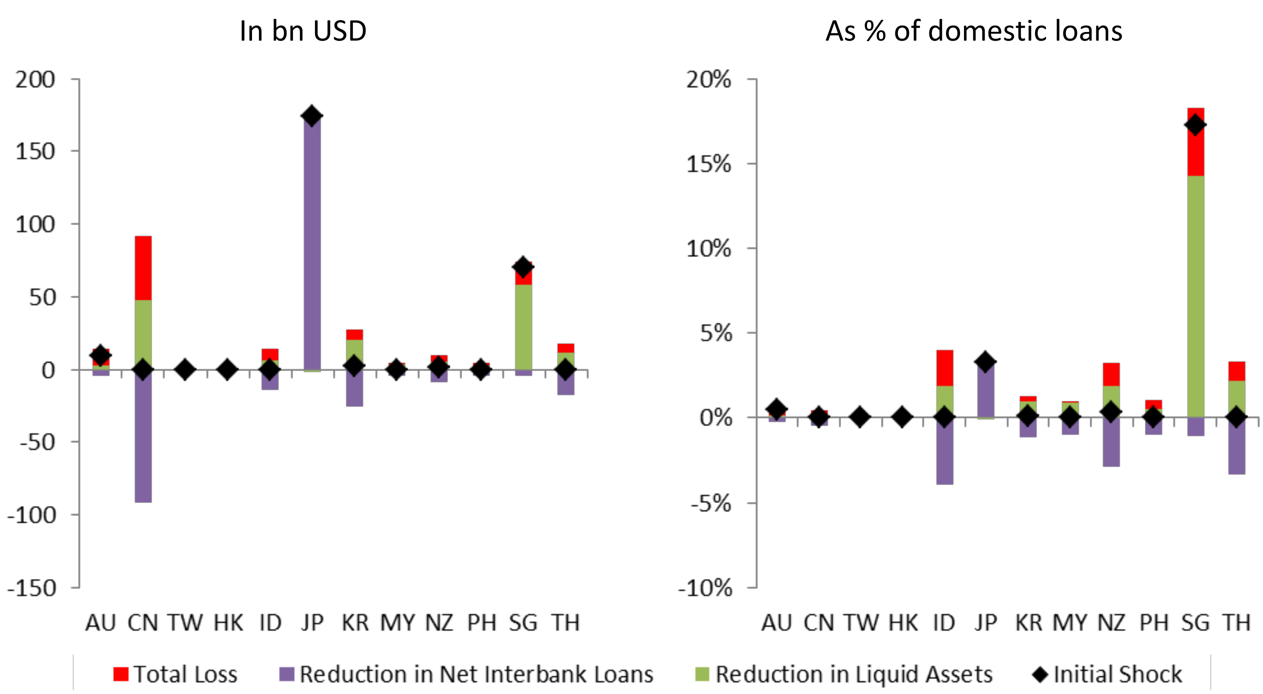
According to Figure 3, distress events—total loss larger than zero--happen in eight out of twelve economies. Given that each economy has the same liquidity ratio, this pattern of loss distribution could be mainly attributed to differences in economies' net liabilities. In an economy with larger cross-border interbank liabilities relative to cross-border interbank claims, it is more likely that this economy will need to liquidate its 'other assets' to satisfy its payment obligations. According to Table 1, Japan and Singapore have the largest net liabilities to AE-4, which explain the large initial shocks received by these two economies. However, unlike Singapore, Japan also has large net claims on the Asia-12 network, which allows it to transmit shocks from AE-4 to the region. Although China has limited net liabilities to AE-4, it has the largest net liabilities to the network of Asia-12, mainly through Hong Kong. Australia and Singapore both have net liabilities to AE-4 and Asia-12, which make them vulnerable to shocks from AE-4 but with relatively low ability to transmit shocks to Asia-12.

Figure 3. Baseline: Size of Total Loss and Initial Shock



Note: total loss is the total amount of 'Other assets' that banks need to liquidate. Domestic loans are defined as bank loans to the private non-financial sector (source: BIS and national central banks).

Figure 4. Baseline: Components of Total Loss

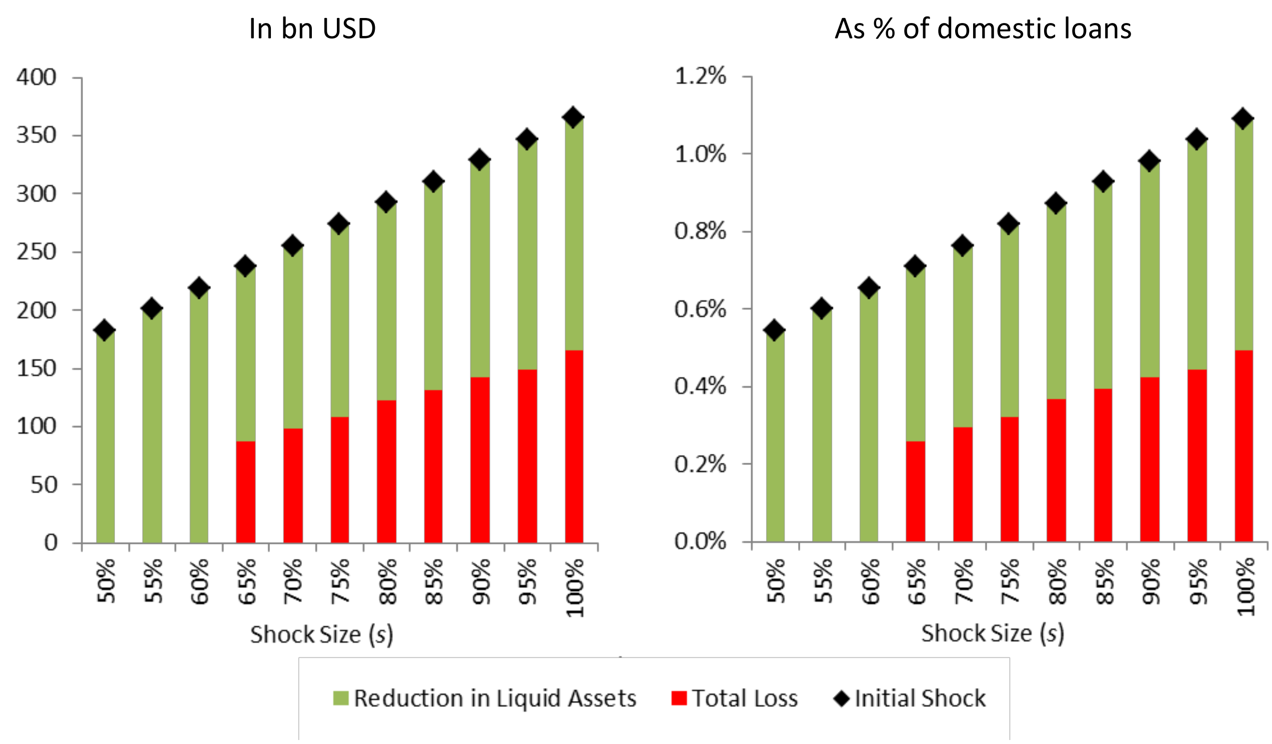


Note: total loss is the total amount of 'Other assets' that banks need to liquidate. Domestic loans are defined as bank loans to the private non-financial sector (source: BIS and national central banks).

Figure 4 further decomposes the initial shock according to the pecking order for liquidating assets. In sequence, the initial shock is covered by reduction in high quality liquid assets—the liquidity buffer, reduction in net interbank loans, and finally total loss (i.e. reduction in other assets). Therefore, the magnitude of the initial shock is equal to the sum of the three. Consistent with Figure 3, Japan coped with the initial funding shock from AE-4 entirely by cutting its interbank lending to other Asia-12 economies. In the case of China, though the initial shock was zero, it was subject to interbank funding cut from Asia-12 and had to liquidate its liquidity buffer and other assets.

Model 2 experiments with different magnitudes of the initial shock, and the results are presented in Figure 5. Two major observations are worth highlighting. First, when the initial funding shock reaches around 65 percent (0.65), the distress event happens; that is, at least one economy in the network needs to liquidate its 'other assets'. Second, there is a positive relationship between the total loss and the magnitude of the shock.

Figure 5. Model 2: Total Loss under Various Shock Sizes



Note: total loss is the total amount of 'Other assets' that banks need to liquidate. Domestic loans are defined as bank loans to the private non-financial sector (source: BIS and national central banks).

Related to model 2, we also test whether a higher liquidity ratio can prevent a distress event, under different assumption of liquidity hoarding behaviour (α). The results are presented in Figure 6. Using the baseline assumption on liquidity hoarding ($\alpha=1$), the current liquidity ratio of the entire banking system of Asia-12, at 50 percent, is sufficient to prevent a distress event from happening, if the initial funding shock is not more than around 60 percent. This is consistent with results presented in Figure 5. However, as the shock size increases, the required liquidity ratio would also increase. When liquidity hoarding is higher/lower than the baseline assumption (α=1.5 or α=0.5), a higher/lower level of initial liquidity ratio would be required to avoid distress events, at a given shock size.

Figure 6. Liquidity Ratio Required to Prevent a Distress Event

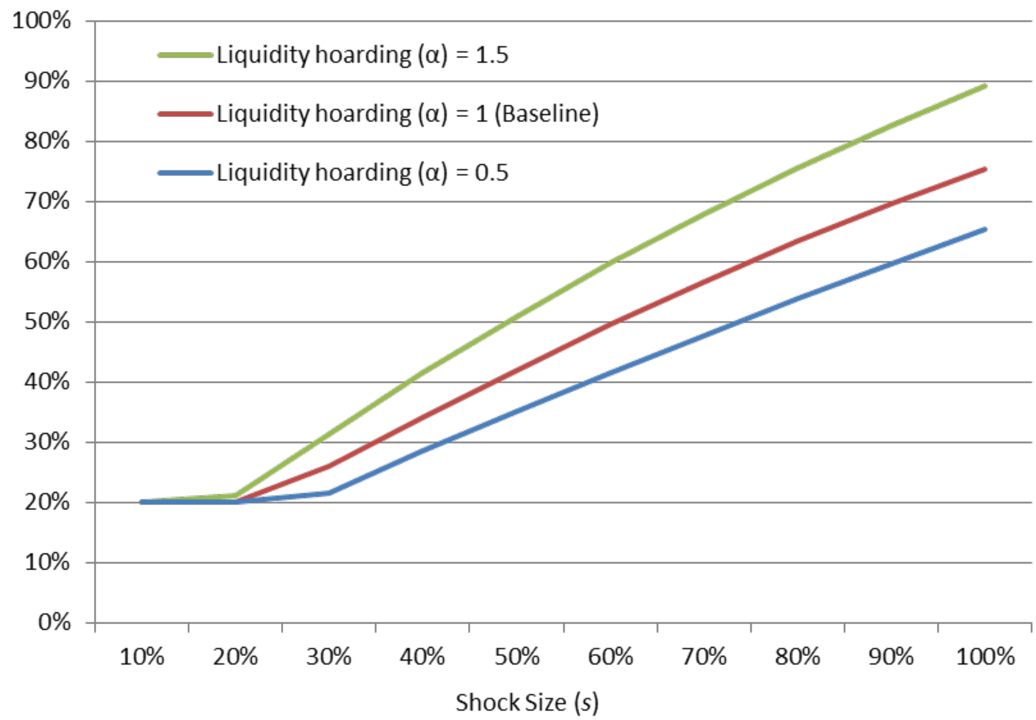
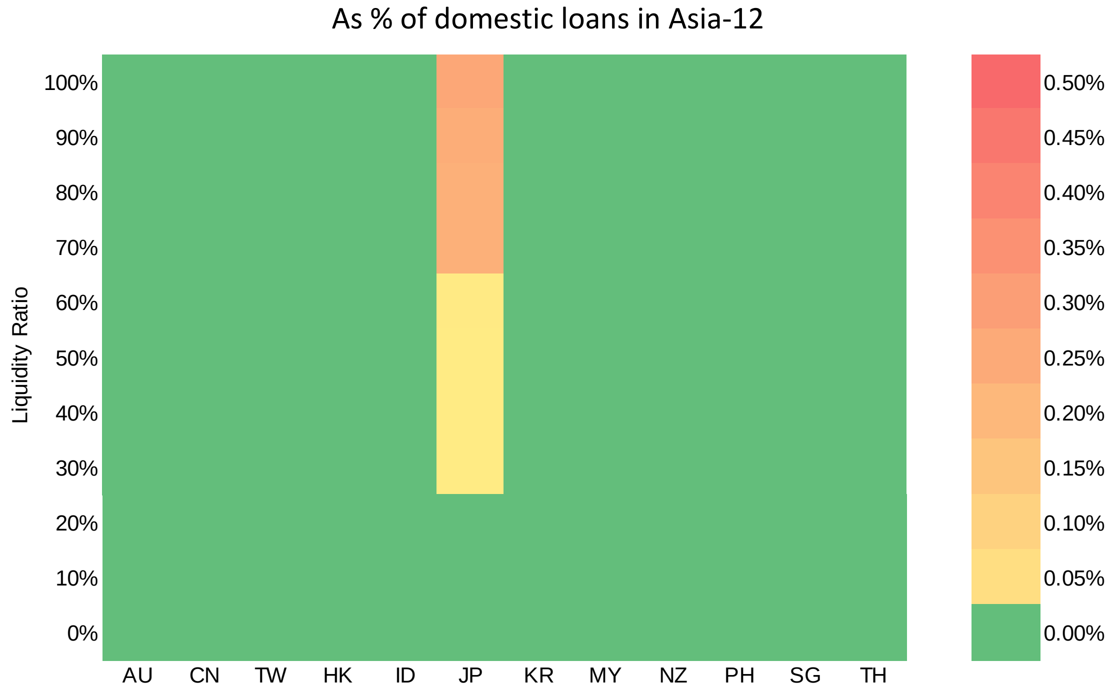


Figure 7 present the results of simulation model 4. This model estimates the total loss (for all economies in Asia-12) if the initial funding shock is only imposed on one economy rather than on all economies in the network of Asia-12. A colour closer to red indicates a higher total loss as % of total domestic loans in Asia-12. The magnitude of this measure is very small because very large economies (e.g. CN and JP) are included in the denominator.

The results show that Japan is the most important link in the network in terms of shock amplification. This finding is likely to be associated with two facts. First, Japan has the largest liabilities to AE-4. Japan's interbank liabilities to AE-4 were around 476 bn USD at 2017Q4, while its interbank credit to AE-4 was lower at 390 bn USD. Its net liabilities to UK were particularly large at 133 bn USD. Second, Japan is one of the largest credit suppliers in the region. In particular, it is the largest credit supplier to regional financial centers, Singapore and Hong Kong. In comparison, Hong Kong has net claims on AE-4, and Singapore is a net borrower from Asia-12.Therefore, both Hong Kong and Singapore have less potential to transmit shocks across the network.

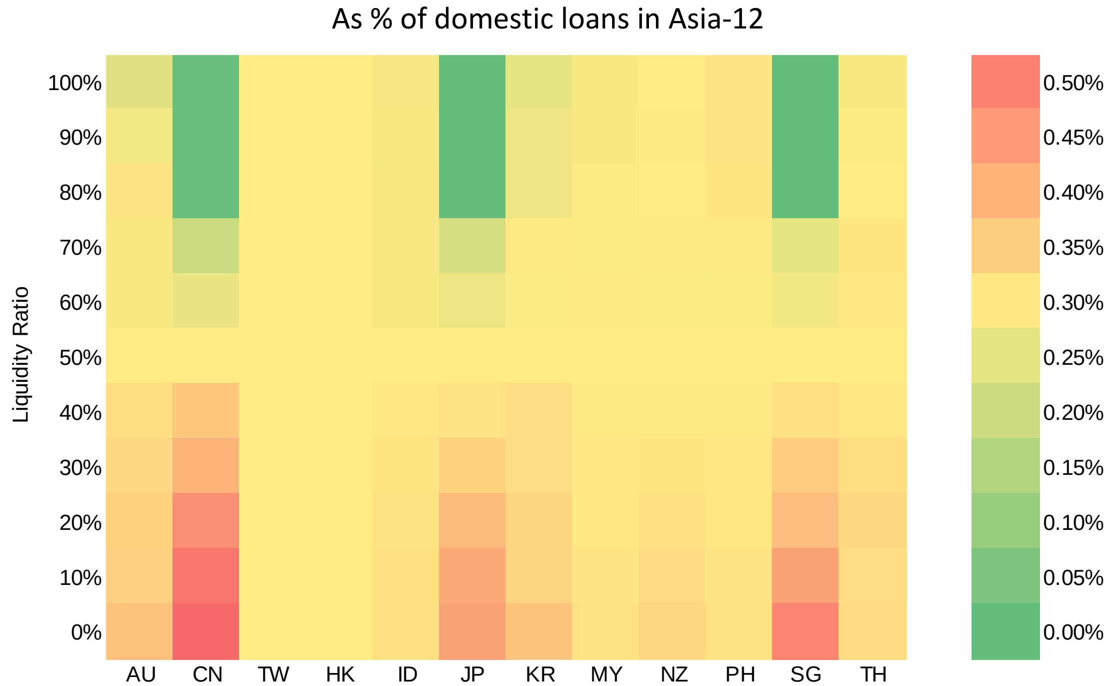
Figure 7. Total loss in Asia-12 under targeted shock: by shock targeting country



Note: total loss is the total amount of 'Other assets' that banks need to liquidate. Domestic loans are defined as bank loans to the private non-financial sector (source: BIS and national central banks).

Figure 8 shows the total loss (for all economies in Asia-12) when we adjust the liquidity ratios of individual economies from 0% to 100%, while keeping other economies' liquidity ratios at 50%. We can see that China, Japan and Singapore are the most 'systemically' important economy in the region. Note that China is 'systemically' important in a different way to Japan: China has very large net liabilities to Asia-12 and is systemically important on its own, while Japan has very large net claims on Asia-12 and is systemically important in transmitting shocks. Singapore is a mixture of both: it is both a core credit supplier to Asia-12 and has large net liabilities to Asia-12 itself (although the latter may be overestimated due to lack of data on Singapore's claims on Malaysia and Thailand). Interestingly, Hong Kong does not have a huge impact despite being an international financial centre, consistent with our earlier findings, which is likely due to its net claims on AE-4.

Figure 8. Total Loss: by different liquidity ratios and economy



Note: total loss is the total amount of 'Other assets' that banks need to liquidate. Domestic loans are defined as bank loans to the private non-financial sector (source: BIS and national central banks).

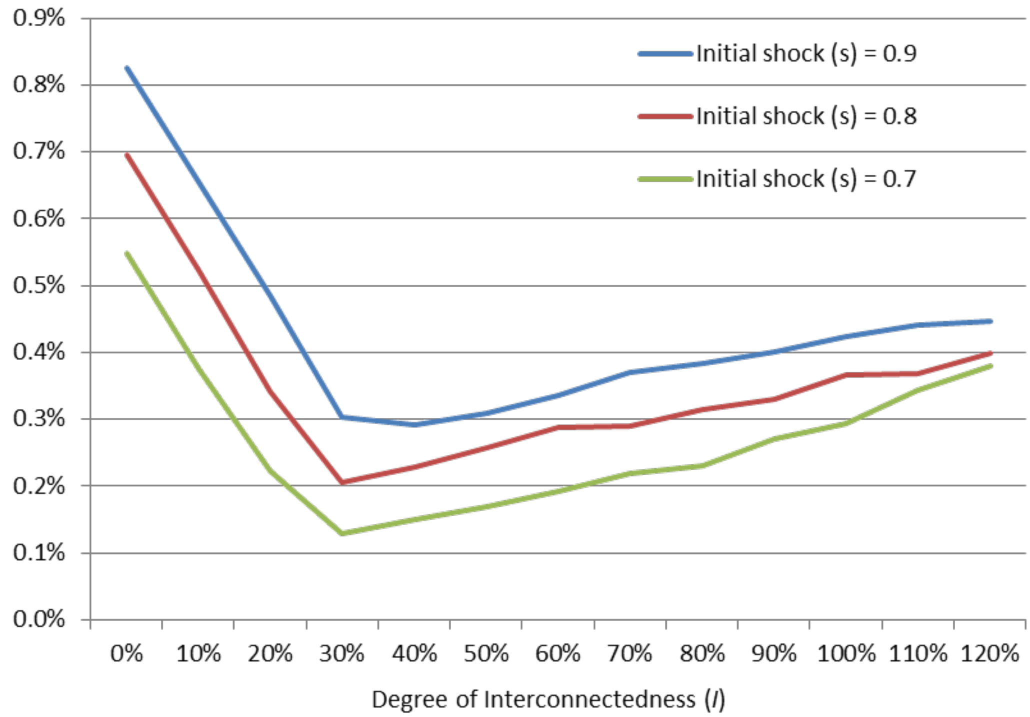
Figure 9 presents total loss under different degrees of interconnectedness and sizes of initial shock. Intuitively, interconnectedness can have two opposite effects on total loss. On the one hand, interconnectedness means that the shock can be shared among countries by pooling excess liquidity buffers in the network, and therefore the impact of the shock can be reduced. On the other hand, interconnectedness means that the economies with external liabilities are more likely to suffer from liquidity hoarding net lenders and the impact of the shock may be amplified.

Figure 9 shows that total loss tend to have a U-shaped relationship with the degree of interconnectedness. This possibly reflects that the risk-sharing effect initially dominates but the liquidity hoarding effect dominates. Moreover, as the size of initial shock increases, the risk-sharing effect tends to become stronger and the liquidity hoarding effect tends to become weaker.[22] A potential explanation is that the risk-sharing effect is more important because when economies do not have enough liquid assets, interconnectedness can help diversify the shocks and increase the resilience of the network. In contrast, when economies have enough liquid assets, risk-sharing has little benefits and the liquidity hoarding effect dominates.

22 By definition, liquidity hoarding increases with shock size.

Figure 9. Total Loss in Asia-12 under different degree of interconnectedness

As % of domestic loans in Asia-12



Note: total loss is the total amount of 'Other assets' that banks need to liquidate. Domestic loans are defined as bank loans to the private non-financial sector (source: BIS and national central banks).

D. Discussions and Important Caveats

Based on the simulation results, the initial liquidity ratio, the magnitude of shocks and each economy's net liabilities are crucial in determining the total loss during a financial stress. In face of higher degree of interconnectedness, and larger shocks, a higher initial liquidity buffer could significantly reduce the probability of a distress event, or reduce the final impact of a shock. It is particularly important for Japan, the most important link in funding shock transmission into Asia-12, to have a high liquidity buffer. It is comforting to know that the US dollar LCR for Japanese banks is more than 100 percent (see IMF, 2018). However, even with a high liquidity buffer, liquidity hoarding behaviour could still amplify the initial shock. Other economies with larger net cross-border liabilities should either try to reduce this liability or increase USD liquidity ratios.

There are a few caveats we would like to highlight in interpreting our results.

First, our network is incomplete, and the network based on 2017Q4 data may not represent the real network at that time. Some Asian economies with liabilities to Asia-12 are excluded, as a result of data limitation. For example, some Malaysia banks have subsidiaries in Cambodia, Vietnam or India, but claims of Malaysian banks on these economies are not counted in our network. Also, bilateral claims between CN, ID, MY, NZ, SG and TH are not available. In addition, net liabilities based on LBS could differ greatly from the net liabilities based on CBS. However, when we use randomly generated network of exposures, results do not change qualitatively, although the importance of economies in the network change as a result of different bilateral positions.[23]

Second, we do not try to label which economy is the most vulnerable, largely due to data limitations. In particular, we didn't consider the heterogeneity in the liquidity ratios of economies in the network. It is likely that economies with relatively higher interbank liability based on LBS data could have a higher liquidity ratio.

Third, we do not differentiate banks within an economy, which are modelled as a single representative bank. Banks diverge massively in terms of their risk exposures, liquidity ratios and behavior, which are not captured by our assumption.

Fourth, cross-border interbank funding involves various currencies, including US dollars, euro, and Japanese yen. Chinese yuan, in the case of funding between HK and CN, is also often used in cross-border funding. Our simulation focuses on aggregate FX-denominated interbank funding and ignores FX movements. However, using the network of USD-denominated interbank claims based on restricted data does not change our findings qualitatively.

V. Conclusions

This paper uses network analysis to study the impact on interbank funding shocks on 12 Asian economies. Results suggest that economies with net cross-border interbank liabilities tend to be more vulnerable, but sufficient liquidity buffer could enhance the resilience of the banking system in face of shocks. In addition, economies that have large interbank claims are more likely to transmit shocks to other economies.. Network configuration also plays a role in the shock transmission: a more interconnected banking system may either aggravagate or mitigate the shock depending on the level of the interconnecteness and other factors, such as the size of shocks.

Despite important caveats, this study aims to enhance the understanding of the resilience of the interbank network in Asia in three major aspects. First, by using the network approach, we illustrate how a FX funding shock is transmitted across Asian economies via both direct and indirect linkages. Second, we provide argument for maintaining a sufficient FX liquidity ratio and reducing net external FX liabilities. Third, the simulation model constructed in this paper could be a helpful tool for policy makers, by using more granular data, to conduct their own stress test for cross-border interbank funding shocks.

23 Results are available upon request.

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