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by

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August 2019 Discussion Paper No. 114

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17 August 2019

Abstract

This paper conducts in-depth profiling of players and interlinkages in the Thai financial system based on sectoral balance sheet data and disaggregated supervisory data on banks and mutual funds. Several aspects of Thailand's financial landscape have been documented. We find that financial interconnectedness has risen and become more complex, with the financial landscape increasingly tilted toward non-bank intermediaries. Network topology suggests a segmented landscape, with the presence of a core cluster where key players including households, firms, large domestic banks, and mutual funds of large banks' asset management arms are located, indicating their tight interconnections. Leveraging on entity-level balance sheet profiles, we develop a stress-testing framework that is based on a network model of financial contagion. Two types of shocks are studied. For industry shocks, we find that losses generally propagate via the liability and ownership channel and the reverse liquidity channel. But when the losses are large enough, the fire-sale effects dominate. For bank reputational shocks, we simulate a loss of confidence in major banks via deposit withdrawal and fund redemption. While the overall losses are much smaller than those of industry shocks, these risks cannot be ignored since the mutual fund industry stands to suffer and panic selling could amplify the losses.

JEL classification: C63, D85, E44, G01, G12, G13, G20, L14.

Keywords: financial networks, financial stability, systemic risk, contagion, fire sales, stress testing, bank and non-bank financial intermediation.

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1. Introduction

With the rise in complexity and interconnectedness in modern financial markets, national regulators' success in safeguarding financial system stability has become increasingly dependent on their ability to understand the financial system as an integrated whole and coordinate their policy efforts accordingly. This requires a thorough understanding of financial interlinkages among households, firms, non-residents, and government via financial intermediaries and capital markets. To achieve this, empirical profiling of financial interlinkages needs to be conducted both at the *aggregate* level to document the role that each sector plays and at a *sufficiently granular* level to yield insights into shock propagation among players.

As a pioneering work in this direction, this paper conducts in-depth profiling of Thailand's financial landscape, with focus on profiling key players and their financial interlinkages through the lens of balance sheets. Using balance sheets allows us to see into the structure of each player's assets and liabilities, which could yield insights into the player's role in the financial system and highlight mismatches that could be conducive to a build-up of risks. Combining players' balance sheets into a *system* of balance sheets also serves as a setup that captures all financial interlinkages in a consistent manner, as one player's assets are mapped to another player's liabilities. Shock transmissions during stressed times could also be traced from players' balance sheet linkages and dynamics.

This study involves two main parts: *profiling* and *stress-testing*. For the *profiling* part, we view the entire financial system as a nexus of interconnected balance sheets, and use sector-level balance sheets to characterize balance sheet interlinkages among main economic sectors. Aggregate profiling based on balance sheet structures, counterparties, and financial instruments is conducted. To delve more deeply into the granularity of entity-level interlinkages, we then construct the Disaggregated Balance Sheet Network (DBN), which is a consistent system of balance sheets with disaggregated balance sheet profiles of non-financial corporations, banks, and mutual funds. This is a data-intensive exercise that leverages on multiple databases, especially the supervisory databases at the Bank of Thailand (BOT) and the Office of the Securities and Exchange Commission (SEC). Network topology of Thailand's financial landscape, as captured by the DBN, will also be explored.

For the second part of the study, we then develop a *stress-testing* framework to test the resiliency of the Thai financial system in the face of shocks. The DBN will serve as the main platform for our stress-testing exercise. Using actual interlinkages allows us to obtain stress-testing results that are grounded in empirical reality and highly informative especially on the cross-sectional dimension of systemic risks. Our stress-testing framework captures three shock transmission channels: the liability and ownership channel, the reverse liquidity channel, and the market channel (i.e. fire sales). Two shock amplification effects, namely panic selling and bank deleveraging, are also included to model players' behaviors during stressed times. Given our profiling and stress-testing results, lessons will then be derived on financial stability oversight and steps toward creating a more resilient financial system.

Our stress-testing framework is related to the literature on network models, which have become widely accepted tools for studying stability and contagion in financial systems. The literature uses linkages of liabilities to form networks of banks. Eisenberg and Noe (2001) provide a model of debt clearing among defaulted and non-defaulted firms when they are linked through a network of liabilities. Acemoglu, Ozdaglar, and Tahbaz-Salehi (2015) use a network of liability linkages to study the effects of network topology on the system's fragility to shocks. Fischer (2014) develops a framework to price assets in a

network with liability linkages and cross ownerships. Many have included the fire-sale effects as channels of contagion in their studies. Cifuentes, Ferrucci, and Shin (2005) propose a network model of interconnected financial institutions that are subject to regulatory solvency constraints and include the fire-sale effects in the model. Chen, Liu, and Yao (2016) study the interactions between the contagion channels through the liability linkages and the asset prices, and conclude that the fire-sale effects can lead to system-wide contagion. Greenwood, Landier, and Thesmar (2015) study the effects of fire sales on banking systems when banks deleverage to their targets. For a recent review of financial contagion models, we refer readers to Glasserman and Young (2016).

The rest of the paper is structured as follows. Section 2 describes data sources and the construction of the Disaggregated Balance Sheet Network (DBN). Section 3 presents empirical profiling of Thailand's financial landscape. Section 4 conducts stress-testing exercises based on a network model of financial contagion. Section 5 discusses policy implications and areas for further research. Section 6 concludes.

2. Data

2.1 Macro-level: the intersectoral balance sheet matrix

We base our aggregate-level analysis on BOT's sectoral balance sheet statistics, which provide aggregate estimates for financial assets and liabilities of main economic sectors in the Thai financial system. These sector-level balance sheets can be further integrated into an *intersectoral balance sheet matrix*, which is an internally consistent system of balance sheets that links one sector's financial assets to another sector's financial liabilities. The intersectoral balance sheet matrix is compiled from an extensive selection of economic and financial databases, which are chosen to capture all financial relationships that take place both directly (i.e. direct financing via capital markets) and indirectly (i.e. via financial intermediaries). Some estimations and adjustments are involved so as to fill in data gaps and make the intersectoral matrix consistent.

Provided that each sectoral linkage involves two counterparties, there might be multiple data sources that capture the same relationships, and in practice the multiple data sources might not align perfectly, resulting in discrepancies between financial assets and liabilities. In some financial relationships, it might also be the case that one counterparty provides data that are more complete, perhaps due to more stringent reporting requirements (e.g. loan data provided by banks are regarded as more complete than those provided by households through surveys). In such cases, data (or *counterpart* data) from the source that is deemed to be more complete and accurate will take precedence in the compilation process.¹

We now briefly discuss on the classification of players and financial instruments, which is essential for understanding further discussions in this paper.

¹ In a descending order of data reliability: central bank, other depository corporations, other financial corporations, international investment positions and external debts, and counterpart data.

With some modifications on the standard taxonomy in the 2008 System of National Accounts (SNA), the balance sheet approach (BSA) by the International Monetary Fund (IMF), and earlier works related to sectoral balance sheets (e.g. Mathisen and Pellechio (2006)), we *sectorize* players in the financial system into seven mutually exclusive sectors based on broadly similar functions, behaviors, and economic objectives. The seven aggregate sectors are as follows:

- Central bank (CB): This consists of the BOT.
- *General government (GG):* This includes central government, local government, and social security fund.
- Other depository corporations (ODCs): These are financial institutions (FIs) that take deposits. Key entities in this sector are commercial banks, foreign bank branches and subsidiaries, government's specialized financial institutions (SFIs) that take deposits, savings cooperatives, and money market funds (MMFs). In this paper, we might refer to these entities as "banks" for brevity.
- Other financial corporations (OFCs): These are the remaining financial corporations. Key entities in this sector are mutual funds (excluding MMFs), life and non-life insurance companies, securities companies, asset management companies (AMCs), leasing companies, as well as credit card and personal loan companies.
- *Non-financial corporations (NFCs)*: These consist of all private and public corporate enterprises that produce goods or provide non-financial services. Examples are listed and unlisted companies outside the financial sectors, as well as state-owned enterprises. We might refer to this sector as "firms" for brevity.
- Households and non-profit institutions serving households (HHNPISHs): These include households and non-profit institutions serving households (NPISHs), which are non-profit institutions that provide goods and services to households and are not mainly controlled by government. We might refer to this sector as "households" for brevity.
- Rest of world (ROW): This consists of non-resident institutions and individuals.

Note that these sectors are defined institutionally. The first six sectors make up the whole domestic financial system, and the ROW sector represents units outside the domestic financial system. For each sector, players' financial balance sheets are aggregated into a single representative balance sheet, which can be interpreted as capturing the characteristics and behaviors of entities within the sector.

Classification of financial assets and liabilities by type of financial instrument

In this paper, financial assets and liabilities are classified by type of financial instrument into seven broad categories, which are substantially different in their liquidity, maturity, and legal characteristics. Most of the classification here follows the 2008 SNA, with some modifications to simplify analysis. The seven categories are as follows:

- Currency (CUR): This consists of notes and coins issued by monetary authorities.
- *Deposits (DEP)*: These include claims that are represented by evidence of deposit, usually involving debtors giving back the full principal amount to creditors. For some part of this paper, currency and deposits might be lumped together into *currency and deposits (CURDEP)*.

- *Debt securities (DBSC)*: These are *negotiable*² financial instruments that serve as evidence of debt, including bills, bonds, negotiable certificates of deposit, commercial papers, debentures, and similar instruments.
- *Loans (LOAN)*: These are non-negotiable financial instruments that are created when creditors lend funds to debtors.
- *Equities (EQTY)*: These financial assets acknowledge claims on the residual value of a company after the claims of all creditors have been met. They can be divided into listed shares (i.e. listed on an exchange), unlisted shares (i.e. private equity), and other equities.
- *Investment fund shares (IFS)*: Theses are shares issued by investment funds, which are collective investment undertakings through which investors pool funds to invest in financial or non-financial assets.
- Other financial assets (OTHER): These represent the remaining financial instruments, including three broad subgroups: (i) insurance, pension, and standardized guarantee schemes; (ii) financial derivatives and employee stock options; and (iii) other accounts receivables and payables.

Financial assets and liabilities can also be classified by many other criteria, and the choice ultimately depends on the specific dimensions of financial relationships that researchers are interested in. In some part of this paper, we will also classify financial assets and liabilities by their original maturity into *short-term* (i.e. repayable on demand at the request of the creditor, or in less than one year), *long-term* (i.e. repayable at some date in one year or beyond), or *unspecified* (i.e. having no stated maturity). For this paper, the breakdown into short-term and long-term maturity applies only to deposits, loans, and debt securities. Other financial instruments are assumed to have unspecified maturity.

It should be noted that, while a more detailed breakdown of financial instruments is available, we view this classification as sufficiently detailed in capturing the different natures of financial relationships in the financial system. This classification scheme is also a direct result of our decision to abstract away from the complicated details in certain classes of financial instruments (e.g. options, insurance technical reserves, etc.), which are either contingent in nature or too complex for the purpose of this paper, given the high level of discretion involved in estimating such balance sheet exposures.

The intersectoral balance sheet matrix

Based on our classification of players and financial assets, each aggregate sector has 14 balance sheet items in the main intersectoral balance sheet matrix: seven for the asset side and seven for the liability side, corresponding to the seven types of financial instruments. With seven aggregate sectors, this translates into a 98x7 matrix that summarizes all cross-sectoral and intra-sectoral financial linkages in the Thai financial system at a given point in time. The time series of this intersectoral balance sheet matrix, spanning over the period of 2011Q1-2017Q4, serves as the main dataset for the profiling exercise to be conducted in Section 3. Note that we will deal with the *non-consolidated* version of sectoral balance sheet statistics, which means that transactions within the same sector are also recorded.

² A financial asset is *negotiable* if its legal ownership is readily capable of being transferred from one unit to another unit by delivery or endorsement. Debt and equity securities, for example, are negotiable instruments that are designed to be traded usually on an organized exchange or in an over-the-counter (OTC) market (2008 SNA).

Although intersectoral balance sheets are useful in profiling the financial landscape and assembling cross-sectoral linkages at the aggregate level, they are not detailed enough to capture entity-level interlinkages, which are essential in understanding how shocks propagate throughout the financial system. To serve as the main platform for our stress-testing exercises in Section 4, we construct the Disaggregated Balance Sheet Network (DBN), which is an internally consistent system of balance sheets that contains disaggregated information on balance sheet interlinkages. In the DBN, the original intersectoral balance sheet matrix is substantially augmented with highly disaggregated data for three groups of entities, namely: *non-financial corporations, banks, and mutual funds*. In the first phase of this project, we incorporate non-financial corporations at the industry level, while going more granular for the latter two groups of entities, both of which are financial intermediaries.³

Dimension 1: non-financial corporations

We decompose the aggregate NFC sector into eight NFC industries (seven non-financial industries and one residual player for reconciling discrepancies that could arise). Our classification of industries shown in Figure 2.1 largely follows the standard scheme used by the Stock Exchange of Thailand (SET), with two major differences. First, the entire financial industry (FINCIAL) has been removed from our classification, since these eight NFC industries are designed to capture only *non-financial* entities. Moreover, financial entities are already represented elsewhere in the DBN (i.e. as sectors by the ODC and OFC sectors, and individually for banks and mutual funds). Second, the Property Fund and REIT sector has been removed from the PROPCON industry, given the fact that entities within this sector represent non-bank financial intermediation and thus are more appropriately represented in the OFC sector, not the NFC sector.

In constructing the industry-level breakdown of NFCs' balance sheets and interlinkages, we use firmlevel data from Ministry of Commerce's Corporate Profile and Financial Statement (CPFS) database, which provides financial data and key characteristics of all registered firms in Thailand. The database is available on an annual basis with a two-year lag, so in this paper we use the 2015 edition of CPFS, which was the latest available at the time of writing. By combining the 2015 CPFS database with the rest of the DBN, which is constructed from data as of end-2017, we are making an implicit assumption that the overall structure of corporate balance sheets has not changed much in between. All nonfinancial firms in the CPFS database are classified according to our industry classification in Figure 2.1, and firm-level balance sheet items are reclassified into 14 balance sheet items as before. Due to the limited availability of counterparty data, industry-level interlinkages with other players in the DBN are pro-rated from the NFC sector's aggregate interlinkages in the intersectoral balance sheet matrix, using each industry's share in NFCs' total assets.⁴

³ This decision is mainly due to the fact that financial intermediaries play an important role in transmitting and amplifying shocks during stressed times. Moreover, the completeness of supervisory databases at the BOT and the SEC allows us to delve more deeply into banks and mutual funds.

⁴ That is, if households invest 100 THB million in stocks issued by NFCs, and the Property and Construction industry accounts for 30 percent of NFCs' total assets, then we assume for now that households invest 30 THB million in stocks issued by firms in the Property and Construction industry. Although this means we miss out on the fact that some players might have concentrated positions on some industries, we view this assumption to be sufficient for the first phase of this project. In the future, such

Industry	Symbol	Sector
Agro and Food Industry	AGRO	AgribusinessFood and Beverage
Consumer Products	CONSUMP	 Fashion Home and Office Products Personal Products and Pharmaceuticals
Industrials	INDUS	 Automotive Industrial Materials and Machinery Packaging Paper and Printing Materials Petrochemicals and Chemicals Steel
Property and Construction	PROPCON	 Construction Materials Construction Services Property Development
Resources	RESOURC	Energy and UtilitiesMining
Services	SERVICE	 Commerce Health Care Services Media and Publishing Professional Services Tourism and Leisure Transportation and Logistics
Technology	TECH	Electronic ComponentsInformation and Communication Technology

Figure 2.1: Classification of industries for non-financial corporations (NFCs)

Note: This classification largely follows the classification scheme used by the Stock Exchange of Thailand (SET). Two key differences are that: (1) the entire financial industry (FINCIAL) has been removed, since entities within this industry are already represented in the DBN (in the ODC and OFC sectors, and individually for banks and mutual funds); and (2) the Property Fund and REIT sector has been removed from the PROPCON industry.

Dimension 2: banks

As the second dimension of our refinements, we incorporate all deposit-taking banks into the DBN *individually*. Our coverage includes all 36 deposit-taking banks operating actively in 2017Q4, which consist of commercial banks, foreign banks' branches and subsidiaries, and SFIs that take deposits. Bank-level detailed financial data are obtained from BOT's Data Management System (DMS). To form a complete picture of individual banks' balance sheet exposures and financial interlinkages, we employ four databases from the DMS: (1) the Balance Sheet (BLS) database, which contains detailed information on individual banks' balance sheets; (2) the Arrangement Summary (ARS) database, which contains a detailed breakdown of banks' outstanding positions by type of financial instrument and other criteria (e.g. term range and remaining term range); (3) the Loan Arrangement (LAR) database, which contains contract-level data on loans given to firms and individuals that have a total credit line or a loan outstanding above 20 THB million with a particular bank; and (4) the Investment Position (IVP) database, which contains contract-level data on investment positions along with information on counterparty, instrument type, and cost value.

holdings could be estimated more accurately by integrating the DBN with securities depository databases, such as data from Thailand Securities Depository (TSD).

It should be noted how the four databases complement one another. The BLS and ARS databases contain bank-level balance sheet items that are the most complete, so they are used to construct and reconcile banks' overall balance sheet exposures. Then, counterparty data from the LAR and IVP databases are used to fill in the granular details to form banks' balance sheet interlinkages with other players in the DBN. Although the LAR database has a minimum reporting threshold of 20 THB million credit line or loan outstanding, and thus leaves out smaller loans, it still contains detailed exposure structures that could be used to construct reasonable estimates of banks' balance sheet exposures to other players in the DBN with some simplifying assumptions.⁵

Figure 2.2 presents some descriptive statistics for 36 banks that are included in the DBN. We present the statistics by dividing the banks into four groups: commercial banks that are domestic systemically important banks (D-SIBs), other commercial banks, foreign banks' branches and subsidiaries, and SFIs that take deposits. Panel (a) shows that, as of end-2017, D-SIBs were by far the largest in asset size, followed by large deposit-taking SFIs. Among commercial banks, there was a large gap in asset size between D-SIBs and other commercial banks. In terms of asset base, the smallest D-SIB was still twice as large as the largest non-D-SIB commercial bank. For foreign banks' branches and subsidiaries, there were 15 of them, but altogether they accounted for only about 7.1 percent of banking system's total assets.

Panels (b) and (c) show the balance sheet structures of each group of banks, decomposed by asset class. For the three groups of domestic banks, one common characteristic was that 70-80 percent of their assets were loans, while 70-80 percent of their liabilities were in form of currency and deposits. In contrast, foreign banks' branches and subsidiaries had different balance sheet structures. On the liability side, one-third of their funding was in form of equities, which is reasonable given that they might rely on funds from their parent banks abroad, while about a half came from currency and deposits.⁶ On the asset side, they invested almost one-third of their assets in debt securities and did not engage much in giving out loans compared to domestic banks.

⁵ For instance, we assume that banks' loan exposures to NFC industries in the LAR database represent banks' overall loan exposures (i.e. banks' loan exposures across NFC industries are assumed to be constant across loan sizes).

⁶ It should be noted that regulation might also play a role here in explaining the high proportion of equities among foreign banks' branches and subsidiaries. According to the Notification of the Ministry of Finance dated 7 June 2013, foreign banks were allowed to submit new requests for setting up subsidiaries in Thailand. One requirement was a minimum paid-up capital of 20 THB billion. This means foreign banks' subsidiaries that were set up under this requirement would have higher equities than those that had been set up earlier.

Bank type	Count	Total assets (THB bn)	Min	Median	Max
Commercial banks • D-SIBs ^{1/} • Others ^{2/}	5 10	12,922.0 3,754.9	1,999.8 45.2	2,725.6 266.7	2,970.0 954.5
Foreign banks' branches and subsidiaries	15	1,709.8	11.7	49.8	448.2
Deposit-taking SFIs	6	5,690.2	71.7	585.2	2,663.8
Total	36	24,076.9			

Figure 2.2: Summary statistics for banks' balance sheets (2017Q4)

(a) Descriptive statistics of banks' assets

(b) Breakdown of banks' assets and liabilities by asset class



(c) Breakdown of banks' assets and liabilities by asset class (percent)



Note: 1/ Domestic systemically important banks (D-SIBs). 2/ We define this category to also include Thai Credit Retail Bank (TCR). For asset classes, refer to Section 2.1 for abbreviations. Note that in this figure, OTHER includes both other financial assets and non-financial assets. Sources: BOT and authors' calculations.

Dimension 3: mutual funds

Next, we incorporate details on mutual funds using SEC's comprehensive database on mutual funds' balance sheets, which contains complete balance sheets of all mutual funds as reported by asset management companies (AMCs). On the asset side, individual securities that each mutual fund invests in are recorded, along with other key information such as cost value and current market value. This enables us to reconstruct mutual funds' portfolio holdings. To simplify analysis and reduce the dimension of the DBN, we aggregate each AMC's mutual funds by fund policy, which reflects the primary asset class that each mutual fund invests in. Based on fund policy, we aggregate each AMC's mutual funds into five groups, namely: *equity, fixed income, alternative investment, mixed, and other funds*.⁷ This is reasonable given that, for funds of the same policy and within the same AMC, there should be a substantial overlap in fund managers and strategies, which could give rise to correlated behavior. In addition, there are two key advantages of classifying mutual funds in this way. First, this classification is mutually exclusive, which prevents double-counting. Second, this classification helps reduce the impact of entry and exit especially among short-term fixed income term funds.

With 23 AMCs and five fund policies, there are 115 entities (i.e. AMC-policy pairs) that represent mutual funds in the DBN. Balance sheets and interlinkages of mutual funds within the same AMC and having the same fund policy are aggregated into a single representative balance sheet. 55 types of financial instruments present in the database are reclassified into seven broad categories, as before, to align with the rest of the DBN.

Figure 2.3 presents some descriptive statistics for 1,342 mutual funds by 23 AMCs as of 2017Q4, all of which are represented in the DBN.⁸ We provide statistics only on the asset side of mutual funds' balance sheets, given that the liability side is almost entirely composed of fund shares sold to unitholders. Panel (a) shows that mutual funds' total assets were about 4.6 THB trillion as of 2017Q4, more than half coming from fixed income funds. In terms of headcounts, the number of equity funds was the highest, although an average equity fund was about one-third the size of an average fixed income fund. Panel (b) shows portfolio weights by asset class, computed at the fund policy level. For equity and fixed income funds, it is not surprising that about 60 percent of assets were in equities and debt securities, respectively, but the combination of asset classes is worth noting. About a quarter of the assets of equity funds were invested in fund shares, which shows that some equity funds were partially acting like a feeder fund or a fund of funds. For fixed income funds, one-third of their assets were in deposits. For mixed funds, about half of their assets were invested in equities, with about one-fifth in debt securities and another one-fifth in fund shares. For alternative and other funds, more than 80 percent of their assets were in fund shares, suggesting that many of them were feeder funds or funds of funds.

⁷ Mutual funds are classified into five groups by fund policy, as follows: (1) *Equity funds* are mutual funds that invest no less than 65 percent of net asset value (NAV) in equity securities, averaged in an accounting year. (2) *Fixed income funds* are mutual funds that invest in debt securities, deposits, and other asset classes allowed by the SEC. Investment in equities or warrants is not allowed. (3) *Alternative investment funds* are mutual funds that mainly invest in shares of property funds, infrastructure funds, gold bullions, or derivatives and structured notes that have commodities as underlying assets. (4) *Mixed funds* are mutual funds that invest less than 65 percent of NAV in equity securities or have no specified weights for asset classes. (5) *Other funds* are mutual funds that do not fall into the four groups above.

⁸ Our analysis includes only mutual funds that had a positive net asset value as of 2017Q4.

		•					
Fund and in a	Count	Assets	Breakdown of assets (THB bn)				
Fund policy Count	Count	(THB bn)	DEP	DBSC	EQTY	IFS	OTHER
Equity	541	1,005.1	37.6	36.7	669.4	231.3	30.0
Fixed income	475	2,735.0	873.7	1,653.2	0.5	174.0	33.4
Alternative investment	73	81.9	4.6	0.3	2.9	69.6	4.5
Mixed	244	770.6	19.9	138.0	431.2	173.5	8.0
Other	9	3.4	0.1	0.1	0.3	2.8	0.0
Total	1,342	4,595.8	936.0	1,828.2	1,104.4	651.3	75.9

Figure 2.3: Summary statistics for mutual funds' balance sheets (2017Q4)

(a) Descriptive statistics of mutual funds' assets

(b) Portfolio weights by fund	policy	۲V
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Fund policy	Breakdown of assets (percent of fund policy's assets)					
Fund policy	DEP	DBSC	EQTY	IFS	OTHER	
Equity	3.7%	3.6%	66.6%	23.0%	3.0%	
Fixed income	31.9%	60.4%	0.0%	6.4%	1.2%	
Alternative investment	5.6%	0.3%	3.6%	85.0%	5.5%	
Mixed	2.6%	17.9%	56.0%	22.5%	1.0%	
Other	3.4%	3.7%	8.3%	84.0%	0.6%	
Overall	20.4%	39.8%	24.0%	14.2%	1.7%	

Note: For asset classes, refer to Section 2.1 for abbreviations. Note that in this figure, OTHER includes both other financial assets and non-financial assets.

Sources: SEC and authors' calculations.

The overall architecture of the DBN

Putting all the components together, the full DBN is presented schematically in Figure 2.4. The original intersectoral balance sheet matrix is preserved in the upper left block of the DBN, so cross-sectoral interlinkages are still fully captured in this structure. As discussed, the matrix has been augmented with detailed balance sheet data for non-financial corporations, banks, and mutual funds. Each player in the DBN has 14 balance sheet items, and this translates into a 2338x167 matrix that represents all balance sheet items and interlinkages at a given point in time. This architecture offers an integrated view of macro- and micro-level perspectives, which provides a reasonably disaggregated picture of the Thai financial landscape without losing sight of the big picture.



Figure 2.4: Structure of the Disaggregated Balance Sheet Network (DBN)

(a) Overall structure of the DBN

(b) Balance sheet items for each player in the DBN

Assets	Liabilities		
Currency	Currency		
Deposits	Deposits		
Loans	Loans		
Debt securities	Debt securities		
Equities	Equities		
Investment fund shares	Investment fund shares		
Other assets	Other liabilities		

Note: Other assets include other financial assets and non-financial assets. Other liabilities are defined similarly.

In constructing the full DBN matrix, significant data gaps remain and a number of design choices have been made. We discuss some of the important ones below.

Issue 1: balancing sectoral balance sheets with non-financial items

One key difference between balance sheets in the DBN and those in the original intersectoral matrix is the inclusion of *non-financial* assets and liabilities. Balance sheets in the DBN are designed to include non-financial assets and liabilities, while those in the original intersectoral matrix include only financial items. Our decision to include non-financial assets and liabilities in the DBN comes from the fact that most entity-level balance sheets that we use for constructing the DBN are complete balance sheets with both financial and non-financial items, and the two sides of the balance sheets are *equal*. In a typical intersectoral matrix, however, the omission of non-financial balance sheet items often means that the asset side and the liability side of each sector's balance sheet are *not equal*, and thus each

sector would be either a net lender or a net borrower with respect to the rest of the financial system.⁹ To cross-validate entity-level balance sheet data that we compile from the ground up with sectoral balance sheets, we need sectoral balance sheets to be balanced as well by including non-financial balance sheet items.

To *blow up* financial balance sheets into complete balance sheets, we use the 2015 CPFS database to compute the ratio of total assets to financial assets for each group of players.¹⁰ This ratio is used to multiply with financial assets to estimate the full size of balance sheets, which is then assumed to be the size of total liabilities as well. The increases in assets and liabilities after blowing up are assumed to be entirely from non-financial items, and are added with other financial assets and other financial liabilities to create other assets and other liabilities, respectively.

Issue 2: some notes on estimating the liability side

Generally speaking, granular data are much more complete for the asset side of balance sheets. For mutual funds, we have security-level portfolio holdings of each mutual fund on the asset side, which allow us to construct exact linkages between mutual funds and securities' issuers. But on the liability side, we do not know exactly who hold each fund's shares and in what amount. In most cases of missing data (mostly on the liability side), we use pro-rata estimation based on aggregate figures at the sector or industry level. For example, we assume that each mutual fund is held by many groups of investors in the same proportion as the mutual fund industry as a whole. This means, for example, that about 75 percent of each mutual fund is assumed to be held by households. Another example is NFC industries' mutual fund holdings, where detailed data are lacking, and simple pro-rata calculation is used in this case as well. It should be noted that we prefer pro-rata calculation to more advanced computational methods (e.g. the maximum entropy approach as employed in Castren and Kavonius (2009)), which are sometimes used to fill in missing bilateral exposures. This is because we view that such methods could generate artificial variations that could affect our stress-testing results.

⁹ It is normal for financial balance sheets to be unbalanced, especially for non-financial players. In reality, a significant portion of assets and liabilities of non-financial players are non-financial. For non-financial firms, a significant portion of their assets are property, plant, and equipment (PP&E). For households, a significant portion of their wealth is in form of housing and land.

¹⁰ For example, at the aggregate sector level, we use the ratio of total assets to financial assets of 1.02 for the ODC, OFC, CB, and ROW sectors (calculated from commercial banks in the 2015 CPFS database), 1.74 for the NFC sector (calculated from all firms in the 2015 CPFS database excluding government and financial entities), and 1.62 for the GG and HHNPISH sectors (calculated from government entities in the 2015 CPFS database, which can be viewed to reflect non-financial non-corporate resident sectors). Players in the first group are mostly financial entities, so the ratio around one makes sense since most of their assets and liabilities are financial. The higher ratio for NFCs is also reasonable, since for many industries a significant portion of their assets are physical (e.g. PP&E).

3. Profiling Thailand's financial landscape

This section documents empirical profiling of players and financial interlinkages in the Thai financial system. We first provide background discussions on financial intermediation and transformation, which aim to set the stage and provide common terms for discussion in subsequent sections. Then, we profile interconnectedness in the financial system through the lens of sectoral balance sheets, with detailed breakdown by counterparty and financial instrument. A network perspective is then employed to visualize the "flow" of funds at the sector level and characterize network topology using granular balance sheet profiles captured in the DBN.

3.1 Financial intermediation and transformation

A simplified framework for modern financial intermediation

A financial system can be understood as a system that channels funds from *ultimate creditors* (i.e. those who save surplus funds) to *ultimate borrowers* (i.e. those that have a shortage of funds and need to borrow). Figure 3.1 presents a highly stylized diagram that traces the flow of funds from ultimate creditors on the right side to ultimate borrowers on the left, with key balance sheet items included to highlight important linkages. Ultimate creditors are primarily households, which save surplus funds and place their savings with banks and asset managers. On the other hand, ultimate borrowers are mainly non-financial corporations that borrow to fund their business ventures, and households that borrow to fund their spending needs, which could be large purchases (e.g. housing) or even short-term liquidity needs. This core function of the financial system—channeling funds from creditors to borrowers—is central to a well-functioning economic and financial system, since entities with surplus funds (e.g. households) might not be those with profitable investment opportunities (e.g. firms). The existence of financial system allows funds to be directed to more productive activities, thus promoting a more efficient allocation of capital in the overall economy.

Funds can flow from creditors to borrowers via two routes. In *direct finance* (at the bottom of Figure 3.1), borrowers could borrow from creditors directly via financial markets (e.g. by issuing financial securities or borrowing directly). In *indirect finance*, the channeling of funds from creditors to borrowers could take place via financial intermediaries. These financial intermediaries (in the center of Figure 3.1) can be thought of as consisting of two segments: (1) other depository corporations (ODCs), which are mainly commercial banks and other FIs that take deposits; and (2) other financial corporations (OFCs), which consist of entities that conduct some form of lending operations like banks (e.g. credit card and personal loan companies) and entities that manage clients' assets (e.g. mutual funds, pension funds, insurance companies, etc.)

In modern-day financial markets, it is important to differentiate financial intermediation of ultimate creditors' short-term and long-term savings, which are different in nature and often involve different groups of financial intermediaries. Ultimate creditors can be understood as doing two things with their savings: (1) they place their short-term savings with banks, mostly in form of demand deposits, which in turn could be used by banks to finance loans; and (2) they invest their long-term savings with asset managers, who then invest the funds in financial securities issued by firms, government, and non-residents. That is, intermediation of ultimate creditors' short-term savings mainly involves ODCs, while intermediation of ultimate creditors' long-term savings mainly involves OFCs.



Figure 3.1: Schematic diagram for the flow of funds through the financial system

Note: The diagram above is highly simplified and only key balance sheet components are included. The diagram is inspired by Pozsar and Singh (2011) and Mishkin and Serletis (2011).



Figure 3.2: Structure of Thailand's financial institutions system (2011-2017) Breakdown by major institution type

(b) Composition of Thailand's financial institutions system (2011-2017) Percent of financial institutions' assets



Sources: BOT and authors' calculations.

To get a better sense of entities that are operating in the playing field, Figure 3.2 shows the composition of players in Thailand's FIs system by asset size from 2011 to 2017, with FIs classified into ODCs (blue regions) and OFCs (non-blue regions). Figure 3.2 gives an impression of an ecosystem that is fairly diverse. Commercial banks continued to be dominant in terms of asset base, with total assets of 19.3 THB trillion as of end-2017 (45.8 percent of total FIs' assets). Despite commercial banks' dominance, OFCs managed to expand at a much faster pace. OFCs' assets grew from 7.2 THB trillion as of end-2011 to 13.3 THB trillion as of end-2017, or at a compound annual growth rate (CAGR) of 9.1 percent. This was almost twice as fast as commercial banks, whose assets grew from 13.5 THB trillion as of end-2011 to 19.3 THB trillion as of end-2017, or at a CAGR of 5.3 percent. Within the OFC sector, fastest asset growth was observed in mutual funds (excluding MMFs) and life insurance companies, which grew at CAGRs of 14.4 and 12.2 percent, respectively, over the 2011-2017 period. OFCs also gained substantially in terms of asset share at the expense of commercial banks (Figure 3.2 panel (b)). As of end-2011, mutual funds (excluding MMFs) and life insurance companies accounted for 6.9 and 5.6 percent of total FIs' assets, respectively. Six years later, their shares increased to 11.2 and 7.9 percent of total FIs' assets, respectively. In contrast, commercial banks' asset share shrank from 50.6 to 45.8 percent of total FIs' assets over the same period. These developments, which have been ongoing for many years, illustrate structural changes in financial intermediation activities, with the overall financial landscape increasingly tilted toward OFCs especially mutual funds and life insurance companies.

Revisiting the notion of financial transformation

Before delving deeper into balance sheet interlinkages in the financial landscape, it is essential that we revisit the notion of financial transformation and put it in the context of modern-day financial system to provide a common language for discussion in subsequent sections. In short, *financial transformation* can be understood as a process whereby financial intermediaries capitalize on their balance sheet mismatches. A simple example would be a bank that takes demand deposits from households (i.e. short-term liquid liabilities) and extends housing loans to homebuyers (i.e. long-term illiquid assets). In this example, assets and liabilities in this bank's balance sheet exhibit mismatches both in terms of liquidity and maturity, which set the stage for profitable financial transformation. Indeed, there are many common forms of financial transformation that take place in the financial system, as discussed below.

(i) The core tasks of financial intermediaries: liquidity and maturity transformation

Liquidity transformation commonly involves the financing of illiquid assets with liquid liabilities. From the example above, the bank, which funds housing loans (illiquid assets) with demand deposits (liquid liabilities), can be said to engage in liquidity transformation. It is important to note that banks are not the only institutions that facilitate liquidity transformation in the financial system. For instance, openended mutual funds usually allow investors to redeem fund shares on a daily basis or at a relatively short notice (liquid liabilities), though many of them invest in assets that are not particularly liquid such as long-term corporate bonds. Note that investment in listed equities can also be understood in this light. While shareholders hold equity claims over firms' assets and the listed shares can be traded for cash almost immediately in the stock market, a significant portion of the underlying assets are relatively illiquid (e.g. property, plant, and equipment). By the same token, some investment structure such as real estate investment trusts (REITs) can also be viewed in this manner. While the underlying real estate properties and their future income streams are far from being liquid tradable assets, REIT units are listed on the SET and can be traded like a stock. To sum up, all these examples involve a creation of liquid claims that are backed by illiquid assets.

Maturity transformation commonly involves the financing of long-term assets with short-term liabilities, and often comes with liquidity transformation given that long-term maturity often comes with some degree of illiquidity. From the bank example given above, the bank finances housing loans (long-term assets) with demand deposits (short-term liabilities). Note that housing loans cannot be sold easily at a short notice, and thus could be considered illiquid. As is the case with liquidity transformation, banks are not the only institutions that engage in maturity transformation. A good example, again, would be open-ended mutual funds that invest in long-term corporate bonds.

Two remarks are worth noting at this point. First, liquidity and maturity transformation are at the core of a well-functioning economic and financial system. Most importantly, both forms of transformation are critical to the process of capital accumulation. By giving out long-term loans to firms to construct plants, for instance, banks facilitate a creation of real physical assets in the real economy, which could then be utilized for productive uses for many years down the road. Indeed, it is reasonable to say that liquidity and maturity transformation serve as an interface where the financial system and the real economy interact, and that a malfunction in these two key tasks of financial intermediaries could have far-reaching repercussions. Second, it should be highlighted that both forms of transformation could lead to financial stability concerns. For example, a panic redemption of open-ended mutual funds could generate a run-like dynamic that feeds into itself. Given a large-scale redemption, fund managers might be forced to engage in a "fire sale" of assets, which could lead to lower asset prices and trigger further rounds of redemptions by unitholders.

(ii) Other forms of financial transformation: size, credit, and risk transformation

We now discuss three other common forms of financial transformation briefly. *Size transformation* can be understood as a process that aggregates small amounts of savings or investment into a large pool of funds. One example would be a bank that funds a one-billion baht corporate loan using its deposit base, which is simply an aggregated pool of small-sized savings accounts deposited by households. Another example is a mutual fund that might have a minimum order of only one thousand baht per subscription order, but could pool their unitholders' savings to invest in a one hundred million baht's worth of government bonds. A collective investment scheme like this allows retail investors to invest and diversify their financial wealth into financial instruments that otherwise would not be readily accessible to them given the large investment size or the high transaction cost involved. For the remaining two forms of financial transformation, *credit transformation* involves the process of credit quality enhancements by securitization, and *risk transformation* involves the cases where financial intermediaries' assets have higher default risks than their liabilities. Due to the complexity involved, the last two forms of financial transformation are mentioned here for completeness only and will not be discussed further in this paper.

3.2 Interconnectedness through the lens of sectoral balance sheets

In this subsection, we conduct comprehensive profiling of financial interconnectedness in the Thai financial system based on sectoral balance sheets, which are compiled and estimated by BOT's Statistics Department for internal and official uses. Financial assets and liabilities of seven main economic sectors are mapped so that one sector's assets are linked to another sector's liabilities. Based

on this dataset over the period of 2011Q1-2017Q4, three sets of evidence will be presented. The first set of evidence focuses on breaking down the structure of each sector's financial assets and liabilities by counterparty. The second set of evidence decomposes the structure of each sector's financial assets and liabilities by type of financial instrument and maturity. Lastly, the third set of evidence explores sector-level balance sheet interlinkages from a network perspective. Taken together, these will allow us to understand, at the sector level, *who owes what to whom* in the Thai financial system and how players are linked together.

3.2.1 Profiling interconnectedness by counterparty

Panels (b)-(h) in Figure 3.3 present the evolution of financial balance sheets of seven main economic sectors from 2011Q1 to 2017Q4, with breakdown by counterparty. Aggregating these seven sectors' balance sheets, panel (a) presents the summary of financial interlinkages in the entire financial system. For each panel, the diagram illustrates the structure of the asset side of the balance sheet (i.e. owning financial assets issued by whom), along with the structure of the liability side (i.e. owing financial liabilities to whom). Figure 3.4 presents the same set of information in percentage terms, so as to highlight the structure of each sector's financial assets and liabilities along with the cross-sectoral dependence in investment and funding activities.

The true creditors and borrowers: households and non-financial firms

We start with the main ultimate creditors and borrowers, namely households and NFCs, to see where the ultimate creditors place their savings and where the ultimate borrowers obtain funding from. For households, Figure 3.3 panel (d) shows that their financial assets continued to grow over time, from 20.4 THB trillion in 2011Q1 to 36.9 THB trillion in 2017Q4 (CAGR of 8.8 percent). Fastest growth was observed in their claims on NFCs (CAGR of 13.0 percent) and OFCs (CAGR of 10.9 percent). In terms of asset shares, these two linkages grew from 26.6 to 34.6 percent of households' total financial assets, and from 19.0 to 21.7 percent of households' total financial assets, respectively (Figure 3.4 panel (d)). This was at the expense of households' claims on ODCs, which grew only at a CAGR of 5.9 percent over the same period, causing ODCs' share in households' financial assets to decline from 44.8 to 37.0 percent. To some degree, this reflects the fact that equities and mutual funds have become an increasingly important part of households' financial wealth, while households' deposits with ODCs have already hit a plateau in terms of growth. On the liability side, households' financial liabilities expanded steadily at about the same pace as that of assets, from 8.8 THB trillion in 2011Q1 to 15.7 THB trillion in 2017Q4 (CAGR of 8.6 percent). ODCs continued to dominate households' financial liabilities by a large margin, accounting for 67.9 percent of households' total financial liabilities in 2017Q4. Putting the two sides of households' balance sheets in perspective, households' total financial assets were valued at about 2.3 times of their total financial liabilities in 2017Q4.

For NFCs, Figure 3.3 panel (e) shows that their financial liabilities kept growing rapidly, from 26.1 THB trillion in 2011Q1 to 45.7 THB trillion in 2017Q4 (CAGR of 9.1 percent). Looking at the liability side, NFCs owed to a diverse pool of creditors, the top three in 2017Q4 being households (34.8 percent), ROW (26.7 percent), and NFCs themselves (24.9 percent). Importantly, having such a diverse pool of creditors means that vulnerabilities in the NFC sector could transmit to many sectors at once. It should also be noted that households' importance as creditors to NFCs has been rising. Indeed, most of households' claims on NFCs are in form of equities, which represent NFCs' increasing reliance on *direct* financing from households.



Figure 3.3: Financial assets and liabilities of main economic sectors (2011Q1-2017Q4) Breakdown by counterparty sector (amount in THB)

Figure 3.4: Financial assets and liabilities of main economic sectors (2011Q1-2017Q4) Breakdown by counterparty sector (percent of sector's assets or liabilities)



Note: Refer to Section 2.1 for abbreviations. Sources: BOT and authors' calculations.

Financial intermediation activities by ODCs and OFCs are inherently different

As shown schematically in Figure 3.1, financial intermediation by ODCs is the traditional game of liquidity and maturity transformation, which commonly involves taking short-term deposits from households and giving long-term loans to households and NFCs. On the liability side of ODCs' balance sheet, households served as the largest source of funds, amounting to 13.6 THB trillion or 52.0 percent of ODCs' total liabilities in 2017Q4. But the situation was different for the asset side of ODCs' balance sheet, since ODCs also lent to and invested in NFCs. As of 2017Q4, households and NFCs accounted for 40.3 and 26.7 percent of ODCs' total financial assets, respectively. Still, by the sheer size and the two-way nature of the linkages, the linkages between households and ODCs constituted the majority of households' liabilities (67.9 percent in 2017Q4) and households constituted a significant portion of ODCs' liabilities (40.3 percent in 2017Q4). This leads to mutual interdependence between the two sectors, and one sector's resilience is thus vital for the other.

Another fact that is revealed by Figure 3.4 panel (f) is that Thai banks still raised funds primarily through retail funding (i.e. deposits by households), and their reliance on wholesale funding (as reflected by the share of ODCs and central bank in ODCs' liabilities) was rather limited. In contrast to the significant portion of ODCs' liabilities owed to households, only a minute share was owed to interbank players (6.8 percent to fellow ODCs and 0.8 percent to central bank). This is different from developed countries (e.g. the euro area), where a greater degree of reliance on wholesale funding has been observed and cited as a factor that could explain the expansion of ODCs' balance sheets in recent years.

On the other hand, intermediation activities by OFCs grew much more rapidly than those of ODCs, as proxied by rapid growth in OFCs' balance sheets. The only commonality was that OFCs also depended largely on households for funding (60.5 percent in 2017Q4). But a stark contrast could be observed on the asset side of OFCs' balance sheets. Figure 3.4 panel (g) shows that OFCs invested in financial assets issued by almost all other sectors in the financial system, the top three being the NFC, GG, and ROW sectors (accounting for 29.4, 17.7, and 16.3 percent of OFCs' total financial assets in 2017Q4, respectively). In other words, OFCs channeled funds from households to almost all other sectors in the financial system. While a significant portion of households' short-term savings intermediated by ODCs returned to households in form of long-term loans, establishing a potential for feedback mechanism, households' long-term savings intermediated by OFCs went to all other sectors in the financial system.

We could view this from several angles. From households' point of view, the existence of OFCs adds value by providing access to many asset classes and cost-effective diversification. This is especially true for collective investment schemes like mutual funds and long-term savings vehicles like insurance policies, which engage in *size transformation* by pooling unitholders' assets. For all other sectors, the existence of OFCs serves as an alternative source of funding. Nonetheless, from a system perspective, these thickened interlinkages have also made the resilience of OFCs more critical to the health of the overall financial system. A panic redemption in open-ended mutual funds, for example, could generate a run-like dynamic that affects many sectors simultaneously.

Supporting actors: central bank and general government

Lastly, panels (b) and (c) in Figure 3.3 suggest a rather limited degree of involvement by central bank and general government in the Thai financial system. Central bank mainly invested in debt securities

abroad and issued debt securities that were primarily held by ODCs. Meanwhile, general government's financial balance sheet appeared very balanced. It should be noted, however, that this is not common across countries, where central banks could take an active role in shoring up financial sectors or governments could run an ever-growing budget deficit. Such developments would likely translate into central banks' swollen balance sheets or governments' outsized financial liabilities compared to financial assets.¹¹

Net lenders versus net borrowers

We now close this subsection by summing up the role that each sector plays in the financial system by looking at its overall financial assets net of financial liabilities. This can be viewed as the difference between the amount of funds invested and raised by each sector. A positive balance means that the sector has a net financial surplus against the rest of the financial system, which implies that the sector serves as a *net lender* that provides funds to other sectors. In contrast, a negative balance implies that the sector acts as a *net borrower* that borrows funds from other sectors. Figure 3.5 shows the evolution of main economic sectors' net financial assets from 2011 to 2017. From Figure 3.5, it could be seen that households served as net lenders with respect to the rest of the financial system, with a growing financial surplus over the years. Meanwhile, NFCs acted as net borrowers, with a financial deficit that kept growing at a similar pace. While this might seem obvious given households and NFCs' roles as ultimate creditors and borrowers, studies conducted in other countries show that this structure could vary greatly across countries, especially in the financial systems where central bank and government play a more active role.¹² For sectors other than the NFC and household sectors, their roles in this regard appeared limited as the two sides of their balance sheets were roughly balanced, resulting in net financial assets that hovered around zero.

¹¹ For instance, see Kobayakawa and Okuma (2012) for the case of Japan, where the general government sector issued a large amount of Japanese government bonds (JGBs), which translated into the liability side that was larger than the asset side. The general government sector was shown to be in financial deficit (i.e. a net borrower vis-a-vis other sectors) that grew larger over the 1981-2010 period.

¹² A case in point is Japan, where both households and NFCs were in net financial surplus while government's financial deficit grew larger over time. Kobayakawa and Okuma (2012) document that in Japan's case over the period of 1981-2010, the financial surplus of households had been declining, while the financial position of NFCs turned from a deficit into a surplus that eventually was greater than households. The authors attribute these findings to the ongoing secular decline in households' savings rate and domestic investment.



Figure 3.5: Net financial assets of main economic sectors (2011Q1-2017Q4) Each sector's net financial claims on all other main economic sectors

Note: Refer to Section 2.1 for abbreviations. Sources: BOT and authors' calculations.

3.2.2 Profiling interconnectedness by financial instrument and maturity

Given that the who-to-whom perspective in the previous subsection characterizes *who* owns financial assets issued *by whom*, a logical next step is to examine more exactly *what* is issued and owned, which would give us more insights into the nature of cross-sectoral relationships. In this subsection, cross-sectoral balance sheet linkages are viewed by type of financial instrument and maturity. Financial assets and liabilities are divided into currency and deposits (CURDEP), loans (LOAN), debt securities (DBSC), equities (EQTY), investment fund shares (IFS), and other financial assets (OTHER). And to the extent that is possible given available data, currency and deposits, loans, and debt securities are further decomposed by maturity into short-term (ST), long-term (LT), and unspecified (UN). Using the information on instrument and maturity jointly allows us to better characterize liquidity and maturity transformation that are ongoing in the financial system. Figure 3.6 shows the decomposition of financial assets and liabilities of main economic sectors by instrument type and maturity. Figure 3.7 presents the same set of information in percentage terms.

Composition of "stocks" of financial instruments

As a starting point, Figure 3.6 panel (a) characterizes the overall trend and the composition of stocks of financial instruments in the Thai financial system. Note that in panel (a), which represents the entire financial system, financial assets and liabilities for each instrument type must be equal, since one sector's assets are mapped to another sector's liabilities. In aggregate terms, total financial assets and liabilities continued to grow steadily, from 78.5 THB trillion in 2011Q1 to 132.8 THB trillion in 2017Q4, or at a CAGR of 7.8 percent. Fastest growth was observed in investment fund shares, equities, and currency and deposits, which grew annually at CAGRs of 13.8, 9.4, and 8.5 percent, respectively. Slowest

growth was observed in debt securities, which grew at a CAGR of only 4.3 percent. Within debt securities, there seemed to be a divergence in the sense that short-term debt securities shrunk by about 3.9 percent annually, while long-term securities expanded by 7.2 percent annually. This was mainly because of central bank's reduced holdings in short-term debt securities abroad in later years.

Results in percentage terms are presented in Figure 3.7 panel (a), and numerical figures are presented in Figure 3.8 for two snapshots, namely 2011Q1 and 2017Q4. Comparing the two periods, equities and investment fund shares gained shares at the expense of debt securities and loans. More specifically, equities grew from 25.9 to 28.7 percent of total financial assets, and investment fund shares grew from 2.6 to 3.8 percent of total stocks of financial assets, both mainly due to households' increased holdings. On the other hand, the share of debt securities shrank from 17.3 to 13.7 percent of total stocks of financial assets. It should be noted that total stocks of debt securities did grow in absolute terms, but they were outpaced by other types of financial instruments.

Revisiting the household-bank wedlock

We revisit the two-way linkages between households and banks, but now with additional information on financial instruments to illustrate financial transformation (panels (d) and (f) in Figures 3.6 and 3.7). Linking households' assets to banks' liabilities, we see that as much as one-third of households' financial assets were deposits that were short-term (as indicated by dark yellow), while more than half of banks' funding on the liability side came from short-term deposits. In the opposite direction, linking households' liabilities to banks' assets, we observe that about 70 percent of households' financial liabilities were loans that were long-term, and most of these were on the asset side of banks' balance sheets. For banks, this reflects both liquidity and maturity transformation (i.e. using short-term liquid demand deposits to fund long-term illiquid loans), and both forms of transformation mainly involve households.

There are some observations at this point. (1) For households, the amounts of their financial assets and liabilities that had banks as counterparties almost mirrored each other. But households' assets that were invested in non-deposit assets, mainly equities and investment fund shares, did not return directly to households' liability side. This reflects the fact that households have a close, two-way relationship with banks, but a rather one-way relationship with other borrowers. (2) As reflected by their balance sheet structures, banks' dependence on households' deposits as a funding source was much greater than households' dependence on bank deposits as a place for parking their savings. Figure 3.7 panel (d) shows that households' financial assets were invested in deposits, equities, and investment fund shares for about one-third each, and the share of deposits to households' financial assets continued to decline. In contrast, Figure 3.7 panel (f) shows that the majority of banks' funding came from deposits, mostly from households, and the share of deposits to banks' financial liabilities continued to edge higher. This reflects the fact that, while households have many alternatives to invest their savings, Thai banks continue to rely heavily on retail funding and have not started to utilize wholesale funding to the extent observed in other countries.



Figure 3.6: Financial assets and liabilities of main economic sectors (2011Q1-2017Q4) Breakdown by type of financial instrument and maturity (amount in THB)

Figure 3.7: Financial assets and liabilities of main economic sectors (2011Q1-2017Q4) Breakdown by type of financial instrument and maturity (percent of sector's assets or liabilities)



Note: Refer to Section 2.1 for abbreviations. Sources: BOT and authors' calculations.

Financial instruments	2011Q1	2017Q4
Currency and deposits	17.0	17.8
Loans	23.4	22.3
Debt securities	17.3	13.7
Equities	25.9	28.7
Investment fund shares	2.6	3.8
Other financial assets	13.8	13.8

Figure 3.8: Composition of financial assets in the Thai financial system (2011Q1 vs. 2017Q4) Breakdown by financial instrument (percent of financial system's total financial assets)

Sources: BOT and authors' calculations.

Shock absorbers versus shock generators

The decomposition of balance sheets by instrument and maturity also provides a hint into the role that each sector plays in shock transmission mechanisms. Generally speaking, equities and short-term financial instruments are inherently more volatile and responsive to short-term developments, so sectors with most of their financial liabilities belonging to such categories tend to be shock generators that transmit shocks to the rest of the financial system. On the contrary, sectors with most of their financial assets belonging to such categories tend to be shock absorbers, who absorb shocks from the rest of the system with the asset side of their balance sheets.

Figures 3.6 and 3.7 seem to suggest that NFCs acted as shock generators, with about 27.5 THB trillion or 60.1 percent of their financial liabilities issued in form of equities as of end-2017.¹³ The equity portion of firms' balance sheets could fluctuate with their business performances, so this is one channel through which firms' performances could start to send ripples to the rest of the financial system. Note that fluctuations originating from the NFC sector could transmit to other sectors both directly (via direct equity claims) or indirectly (via holdings of fund shares).

On the other hand, key shock-absorbing sectors were the household sector, and to a lesser extent the ROW and GG sectors, as reflected by the substantial size of equities and investment fund shares on the asset side of their balance sheets. As noted earlier, the NFC sector was estimated to have about 27.5 THB trillion worth of equities outstanding, which was held by households (31.5 percent), ROW (27.7 percent), and NFCs (24.8 percent). It is reasonable to say that fluctuations in firms' performances would be absorbed mainly by these three sectors through equity linkages.

In addition, Figure 3.6 panel (h) captures the relationship between the ROW sector and the domestic sectors. From the balance sheet of the ROW sector, foreign assets held by domestic players were mostly debt securities, while domestic assets held by the ROW sector were mostly equities. Given that debt securities tend to fluctuate less than equities, this might imply that the domestic sectors absorbed external shocks from the ROW sector less than the ROW sector helped absorb domestic shocks.

¹³ This represents both listed and non-listed shares, as well as other forms of equities. Note also that a non-negligible portion of NFCs' liabilities are classified as other financial assets. These are other financial items including other accounts payables.

A second look at intermediation by ODCs and OFCs

We have seen earlier that financial intermediation activities by ODCs and OFCs are inherently different in terms of counterparties involved. Panels (f) and (g) of Figures 3.6 and 3.7 show that the compositions of their assets and liabilities were also very different. ODCs mainly engaged in traditional liquidity and maturity transformation, as reflected by the fact that short-term deposits accounted for almost 60 percent of their financial liabilities in 2017Q4, while long-term loans accounted for about half of their financial assets. But for OFCs, financial instruments on the asset side of their balance sheets were diverse, with debt securities, loans, and equities accounting for 41.7, 22.0, and 21.5 percent of their financial assets in 2017Q4, respectively. Compared to loans, debt securities and equities could fluctuate in value, and this could in turn be passed on to holders of fund shares and insurance policies, who are mainly households.

3.2.3 A network perspective on cross-sectoral claims

This subsection explores financial interconnectedness through a network perspective, which is a highly intuitive way to visualize the "flow" of funds through the financial system. In our representation, a network is a geometric construct consisting of two types of elements: *nodes* and *edges*. Each *node* represents a sector, with node size proportional to the sum of the sector's financial assets and liabilities. Each *edge* represents a bilateral relationship between two sectors, with edge thickness proportional to the size of mutual asset holdings between the two sectors (i.e. how much one sector holds financial instruments issued by another). For each edge, the flow of funds goes from the source node to the target node in a clockwise direction. A self-loop, where an edge goes out from and returns to the same node, represents an intra-sectoral relationship.

Figure 3.9 panel (a) illustrates interlinkages among main economic sectors via all types of financial instruments in 2017Q4, which can be further decomposed into six layers, each of which represents interconnectedness via each type of financial instrument as shown in Figure 3.10. For comparison, Figure 3.9 panel (b) presents an aggregate network similar to panel (a) but constructed from 2011Q1 data. These figures can be viewed as a synthesis of the previous two subsections, since these networks combine the information on counterparties and instruments into one geometric structure.

It should be noted that there are two intuitive ways to read these diagrams. First, we can treat these networks as capturing "funding structures". For example, in Figure 3.10 panel (a), the thickest edge going out from the HHNPISH node to the ODC node (in a clockwise direction) represents households' deposits at banks (i.e. funds flowing from households to banks). This would be on the liability side of banks' balance sheets, showing that deposits by households were banks' source of funds. The second way is to read these networks as capturing "shock transmission channels". For example, in Figure 3.10 panel (d), equities issued by NFCs were held mostly by households, ROW, and NFCs themselves. So, if there were an adverse shock to NFCs propagating via equity linkages, the shock would be absorbed largely by these three sectors.

We now discuss briefly on some distinctive features that stand out visually from these networks.

Three pillars of the system: households, NFCs, and ODCs

Figure 3.9 panel (a) shows that households, NFCs, and ODCs served as the main pillars of the financial system. In terms of node size, which reflects overall importance, these three sectors were larger than

other sectors by a wide margin as of 2017Q4. In terms of linkages, these three sectors also had thickest incoming and outgoing edges. As discussed earlier, the household-bank linkages form the core of the financial system and the relationship is two-way. This is visually represented in a network as a "loop", which shows mutual interdependence between the two sectors mainly via deposits and loans (panels (a) and (b) of Figure 3.10).

As ultimate creditors, households provided funds to ODCs via deposits, NFCs via equities, and to a lesser extent, OFCs via investment fund shares. An adverse shock to households would likely imply a liquidity concern for ODCs, NFCs, and OFCs via their respective linkages. As ultimate borrowers, NFCs received funds from households via equities, ROW via equities, NFCs themselves via equities, and ODCs via loans, all of which were significant. So, if there were an adverse shock to NFCs, the shock would be absorbed largely by households, ROW, and fellow NFCs. This characterization applies both for 2011Q1 and 2017Q4.



Figure 3.9: Interconnectedness among main economic sectors (2011Q1 vs. 2017Q4) Interlinkages via all financial instruments

Note: Node size is proportional to the sum of player's assets and liabilities. Edge thickness is proportional to the size of balance sheet linkages. For each linkage, the flow of funds goes from the source node to the target node in a clockwise direction. Refer to Section 2.1 for abbreviations.

Sources: BOT and authors' calculations.



Figure 3.10: Interconnectedness among main economic sectors (2017Q4) Breakdown of cross-sectoral linkages by type of financial instrument

Note: Node size is rescaled in each panel to emphasize relative importance in each asset class. More specifically, node size is proportional to the sum of player's assets and liabilities that belong to the asset class of interest. Edge thickness is proportional to the size of balance sheet linkages. For each linkage, the flow of funds goes from the source node to the target node in a clockwise direction. Refer to Section 2.1 for abbreviations.

Sources: BOT and authors' calculations.

Key players in each market

The six panels in Figure 3.10 could be interpreted as characterizing the market for each type of financial instrument, as only balance sheet interlinkages related to the respective instrument are included. For each panel, node size is rescaled and is proportional to the sum of the sector's financial assets and liabilities. Thus, node size represents each sector's relative importance in a particular market, capturing the sector's role both as an issuer and as a holder of financial instruments. For currency and deposits and loans, ODCs and households dominated, with a non-negligible role of NFCs. For debt securities, the CB, ROW, GG, and OFC sectors were important. Although NFCs and ODCs issued corporate bonds, they still accounted only for a minor share of the entire bond market. For equities, NFCs were the main issuers, with ROW, households, and NFCs being the top holders of NFCs' equities. For investment fund shares, only households and OFCs were important. For other financial assets, households and NFCs were the most important players, with some involvement from OFCs. Note that for other financial assets in panel (f), the outgoing edge from households to OFCs mostly represents households' ownership of insurance policies, and the self-loop for NFCs mostly represents other accounts receivables and payables among NFCs.

Growing importance of OFCs

Figure 3.9 panel (a) shows that most intermediation activities in 2017Q4 still took place via ODCs, which dominated networks of deposits and loans (panels (a) and (b) of Figure 3.10). But comparing panels (a) and (b) of Figure 3.9, it is apparent that intermediation through OFCs grew noticeably over the seven-year period. Indeed, several linkages to OFCs thickened, notably the incoming edges from households via investment fund shares and other financial assets (e.g. insurance policies).

Self-loops in NFCs and ODCs

Self-loops in Figures 3.9 and 3.10, which represent intra-sectoral relationships, were notable only for NFCs and ODCs. For NFCs, the significant presence of self-loop here suggests that there was a feedback mechanism that could cause an adverse shock to NFCs to reverberate within the NFC sector via intrasectoral equity linkages. For ODCs, the self-loop via loans here largely represents banks' wholesale funding through the interbank market. This captures the channel through which an adverse shock to a bank could reverberate within the banking system via interbank loan linkages, although the linkage was rather small relative to the size of banks' overall balance sheets given Thai banks' high reliance on retail funding.

3.3 Network topology of Thailand's financial landscape through the Disaggregated Balance Sheet Network (DBN)

We now make a transition from a sectoral perspective to a micro one, using the Disaggregated Balance Sheet Network (DBN) constructed in Section 2.2. The DBN allows us to take a first look at the granular level of financial interlinkages. While most players still enter the DBN at the sector or industry level, substantial refinements on banks and mutual funds have been incorporated, which should allow us to gain insights into the two financial intermediary sectors (i.e. the ODC and OFC sectors) and their relationships with the rest of the financial system.



Figure 3.11: The Disaggregated Balance Sheet Network (2017Q4) Interlinkages via all financial instruments

Note: Node size is proportional to the sum of player's assets and liabilities. Edge thickness is proportional to the size of balance sheet linkages. For each linkage, the flow of funds goes from the source node to the target node in a clockwise direction. Refer to Section 2.1 for abbreviations.

Source: Authors' calculations.



Figure 3.12: The Disaggregated Balance Sheet Network (2017Q4) Breakdown of linkages by type of financial instrument

Note: Node size is proportional to the sum of player's assets and liabilities that belong to the asset class of interest. Edge thickness is proportional to the size of balance sheet linkages. For each linkage, the flow of funds goes from the source node to the target node in a clockwise direction. Refer to Section 2.1 for abbreviations. Source: Authors' calculations.

Figure 3.11 presents players in Thailand's financial landscape in 2017Q4 as captured by the DBN. The master network here features key players from several levels of aggregation. More specifically, central bank, general government, households, and the rest of the world enter as aggregate sectors as before. NFCs enter as industries (seven orange nodes), deposit-taking banks enter individually (36 red nodes), and mutual funds enter at the AMC-policy level (115 pink nodes). The network contains 8181 edges, with edge color showing the type of instrument and edge width showing the size of cross-holdings of assets. There are six types of edges represented here, with currency and deposits lumped together. As before, funds flow through an edge in a clockwise direction. That is, for each edge linking two nodes, the source node holds assets issued by the target node. Figure 3.12 presents subnetworks for each financial instrument. We discuss on some notable features of the DBN as follows.

Node positions

Although nodes' positions in absolute terms are inherently not interpretable, nodes' positions relative to one another convey important information. First, nodes located closer to one another tend to be more related. More specifically, two nodes located nearby might be connected either *directly* by cross-holding of assets, or *indirectly* by having a common exposure to the same set of players. Second, each node's proximity to the center of the network indicates whether the player is generally well-connected with other players in the financial system. Households (yellow node), NFC industries (orange nodes), and large domestic banks (red nodes near orange nodes) were densely connected with other players in 2017Q4, and this pushes them toward the center of the network. On the other hand, nodes in the outer area tend to be players that have only a few linkages or play a limited role in the financial system.

Three groups of banks

Based solely on their balance sheet profiles and interlinkages as of 2017Q4, banks were self-organized into three broad groups, which indeed corresponded to their characters and involvements in the financial system. The first group of banks were the red nodes in the central cluster of the network, squeezed by pink and orange nodes. These consisted of the six largest domestic commercial banks, along with a few medium-sized banks, which were "in the thick of things". These core banks stayed relatively close to households (yellow node) and dominated households' financial transactions. As seen in panels (a) and (b) of Figure 3.12, these core banks received the majority of households' deposits and gave out the majority of households' loans. These core banks also stayed close to NFCs (orange nodes), given that they also provided the majority of loans received by NFCs. Moreover, most of them also had asset management companies (AMCs) as subsidiaries, which explains their locations right next to the pink nodes representing mutual funds.

The second group of banks, which consisted of only a few, stayed near the large household node but far away from the mutual fund cluster. These were government's large SFIs, which served as important sources of funds for households as indicated by significant loan linkages with the household node (Figure 3.12 panel (b)). However, their relationships to households did not seem to extend beyond loans and deposits, and they were not as involved with NFCs as the first group of banks did.

The third group of banks were the nodes on the far upper right of the household node, most of which were foreign banks' branches and subsidiaries. Their balance sheet interlinkages suggest that their roles in the Thai financial system were limited. Indeed, the closest player to them was central bank (blue node). They were also sparsely located, which means that they were not that related to one

another either. As seen in panels (a) and (b) of Figure 3.12, these banks did engage in loans (mostly interbank loans), with some of them also taking deposits and holding debt securities.

Two layers of mutual funds

Figure 3.11 also shows that mutual funds organized themselves into a core-periphery structure. In the core area, most mutual funds located there tended to be equity and mixed funds that were larger in size and sold by AMCs that were subsidiaries of D-SIBs. Their central position implies that these funds were tightly connected with core players in the financial system. This is partly due to the fact that they tended to invest in multiple asset classes and had large equity linkages with several NFC industries. There are also a few cases where a bank and its mutual funds were located near the same NFC industry. This implies that the bank might be connected with that particular industry in multiple ways. For example, the bank might have large loan exposures to the industry, and its mutual funds might have substantial equity exposures to the same industry.

In the periphery area, mutual funds located there seemed to belong to two groups—either they were sold by AMCs that did not have parent banks, or they were classified as fixed income, alternative, or other funds. In Thailand's case, fixed income funds tend to have limited linkages with NFC industries, given that a substantial portion of their portfolios are in debt securities issued by government and central bank. Connections to NFC industries via holdings of corporate bonds are generally limited. Figure 3.11 also reveals that some fixed income and mixed funds of large banks' AMCs stayed close to general government (green node), and some were feeder funds that had outgoing edges to the ROW sector directly (purple node).

3.4 Special discussion: the mutual fund industry, its structure, and risk transmission channels to the financial system

This section documents the detailed structure of the mutual fund industry, which is the core part of the OFC sector in our network. Both aspects of mutual funds' balance sheets, namely the liability and asset aspects, will be explored. We start with the liability aspect, which reflects the interlinkages between mutual funds and unitholders especially households. We focus on two areas. First, we look at the role of mutual funds as households' alternative savings mechanisms. While banks continue to be the main counterparties for households' savings, mutual funds have been gaining shares rapidly, and the shifting landscape puts the mutual fund industry into the spotlight due to its rising systemic significance. Second, we look at the risk transmission to unitholders, with risk exposures roughly proxied by type of mutual fund. We then turn to the asset aspect, which captures the *de facto* risk profile of the mutual fund industry. By looking at mutual funds' actual asset holdings by asset class and issuer over time, we can track the changing characteristics of investment risks that are absorbed into systemic risks, as well as the risk transmission from other sectors to the mutual fund industry. Looking at both the liability and asset aspects allows us to characterize mutual funds' interconnections with the financial system at large, which could inform policies aiming to contain systemic risks arising from mutual funds.

3.4.1 Liability side: developments of the mutual fund industry in terms of size and diversity

The Thai mutual fund industry has experienced an impressive growth over the last decade both in terms of size and diversity. As shown in Figure 3.13 panel (a), the mutual fund industry's total asset

under management (AUM) expanded from 0.7 THB trillion in 2006 to 4.7 THB trillion in 2018Q2. This was an increase of about 6.7 times over 12 years, or a CAGR of 17.2 percent, which is impressive by any standard. A closer look shows that the growth momentum was robust even amidst the global financial crisis in 2008, and has picked up an accelerated pace since 2011. Foreign investment funds (FIFs) and real-asset mutual funds (e.g. REITs and infrastructure funds) also gained momentum, thereby enhancing the diversity of investment products offered.

The impressive growth of the mutual fund industry has been a result of growth in four major types of funds, namely: FIFs, fixed income funds, domestic equity funds, and real-asset mutual funds. (1) FIFs gained importance in the investment landscape rapidly, with the total AUM growing from 0.2 THB trillion in 2008Q1 to 1.1 THB trillion in 2018Q1. Such growth not only gave households a broad access to investment opportunities abroad via local AMCs, but also increased contagion risks due to higher exposures to foreign markets and economies through FIFs' holdings of foreign assets. (2) Fixed income funds grew from 0.5 THB trillion in 2006Q1 to 2.0 THB trillion in 2018Q2 in terms of total AUM. On top of the observed growth, fixed income funds also experienced a transition in their composition, with the majority of the fixed income fund category shifting from term funds to daily fixed income funds, while the share of MMFs remained stable over the years. (3) Domestic equity funds gained traction steadily and are now a significant part of the investment landscape. Starting from 96.5 THB billion in 2006Q1, the total AUM of domestic equity funds rose to 731.6 THB billion as of 2018Q2, with 60.8 percent of the AUM coming from tax-benefit equity funds.¹⁴ (4) Real-asset mutual funds started to gain momentum in later years thanks to the growing popularity in REITs and infrastructure funds since 2013, with the total AUM growing from 250 THB billion in 2013 to 590 THB billion in 2018Q2. Altogether, the expansion in these four types of funds has boosted the systemic importance of mutual funds in the financial landscape over the past decade, potentially transforming the systemic risk profile of the Thai financial system.

Have mutual funds become bank substitutes?

The rapid growth of mutual funds over the past decade has raised an issue to regulators, particularly on the interconnections between mutual funds and banks, which are represented as OFCs and ODCs in our network. Moreover, mutual funds have different risk profiles compared to banks, so regulators will have to adapt and deal with systemic risks that could arise from mutual funds differently. Given that both mutual funds and banks are competing channels of resource allocation from ultimate creditors (i.e. households) to borrowers, one issue of concern is whether mutual funds have become bank substitutes for households, because this could mean a significant transformation in households' portfolios of assets, which could lead to a different aggregate systemic risk profile.

Panels (a) and (b) of Figure 3.13 show that there was a dual increase in mutual funds' assets and banks' deposits, but the paces of acceleration were different. During the ten-year period from 2008Q1 to 2017Q4, the total AUM of mutual funds grew from 1.2 to 4.8 THB trillion or about fourfold, while the total value of banks' deposits increased from 8.2 to 17.2 THB trillion or about twofold. Although the expansion of mutual funds was twice as fast as that of bank deposits, these data affirm that at the

¹⁴ Based on a previous study, the growth of domestic equity funds between 2010 and 2015 was attributable to two important sources: funds' performances and net investment inflows. These two factors were estimated to contribute 36 and 64 percent, respectively, to the growth of domestic equity funds during the 2010-2015 period. Indeed, out of the 64 percent contribution due to net inflows, key contributors were tax-benefit funds (37 percent from long-term equity funds (LTFs) and 8 percent from retirement mutual funds (RMFs)).
aggregate level: (1) bank deposits continued to be the main destination for households' savings and (2) households did not seem to withdraw their money from bank deposits to invest in mutual funds. This suggests that mutual funds have not become substitutes for bank deposits in households' portfolios.





Note: *Banks' savings products include savings and time deposits offered by commercial banks and SFIs. To specify term ranges, a square bracket indicates that the range is inclusive of the boundary, while a round bracket indicates that the range is exclusive of the boundary. Sources: SEC and authors' calculations.

Rapid growth in mutual funds leads to fast-changing dynamics of risk transmission

The fast-pace expansion of mutual funds poses another challenge to regulators. One distinctive feature of the mutual fund industry is that its composition tends to change guickly, and this could lead to quick changes in the overall risk profile of the financial system. The rapid growth over the past decade has led to significant changes in the sources of risks to Thai households and NFCs, and one example is the increased exposures to foreign economies and financial markets through FIFs, which now account for a significant proportion of the mutual fund industry. Panels (a) and (b) of Figure 3.14 show the compositions of the mutual fund industry and banks' savings products over the past decade. Comparing the two panels, it is clear that the mutual fund industry has been changing more dynamically. For example, the mutual fund industry in 2006 was mainly composed of fixed income and equity funds, along with a small share of property funds. Over the next 12 years, FIFs, infrastructure funds, and REITs gained a substantial market share. Fixed income funds also went through a dynamic structural transition. The share of term funds dominated in 2006-2007, shrank in 2009, then fluctuated and eventually became miniscule as of 2018. On the contrary, daily fixed income funds gained a lion's share of the fixed income fund category. Given faster risk transmission in today's financial markets, the fastchanging composition of the mutual fund industry also means that the resulting risk exposures of the overall financial system could be highly volatile. This phenomenon could add to systemic stress and make it more challenging for regulators to design appropriate policies to contain systemic risks.



Figure 3.14: Compositions of the mutual fund industry and banks' savings products Breakdown by major product type (percentage of total)

Note: *Banks' savings products include savings and time deposits offered by commercial banks (CBs) and SFIs. Sources: SEC and authors' calculations.

3.4.2 Asset side: parent banks' incentives and mutual funds' risk profiles based on actual holdings

The rapid expansion of the mutual fund industry also raises a question regarding the rationale of such fast growth. To understand the phenomenon better, we now explore the asset side of mutual funds' balance sheets. We will look at AMCs' ownership structure to give a rationale for mutual funds' fast-growing asset base, and then at mutual funds' *de facto* risk profiles based on actual asset holdings.

Banks dominate the mutual fund industry

Panels (a) and (b) of Figure 3.15 exhibit developments of the fund management industry¹⁵ and the mutual fund sector in particular. The total AUM in each panel is decomposed into four groups based on AMCs' ownership structure, namely: bank subsidiaries, foreign subsidiaries, securities company subsidiaries, and others.¹⁶ It is clear that the fund management industry as a whole and the mutual fund sector have been dominated by bank-subsidiary AMCs, with more than 90 percent of the total AUM under their management. Their dominant position also seems unchallenged over time. Given the

¹⁵ This is an umbrella term that includes mutual funds, provident funds, and property and infrastructure funds.

¹⁶ All 25 AMCs are classified by ownership structure as follows: (1) <u>bank subsidiaries</u> (BBL Asset Management, CIMB-Principal Asset Management, Kasikorn Asset Management, Krung Thai Asset Management, Krungsri Asset Management, Land and Houses Fund Management, Phatra Asset Management, SCB Asset Management, Thanachart Fund Management, TISCO Asset Management, TMB Asset Management, and UOB Asset Management (Thailand)); (2) <u>foreign subsidiaries</u> (Aberdeen Asset Management, Manulife Asset Management (Thailand), Phillip Asset Management, and Siam Knight Fund Management); (3) <u>securities company subsidiaries</u> (Asset Plus Fund Management, Bangkok Capital Asset Management, One Asset Management, and Solaris Asset Management); and (4) <u>others</u> (Capital Link Fund Management, Finansa Asset Management, Merchant Partners Asset Management, MFC Asset Management, and Talis Asset Management).

fact that bank-subsidiary AMCs are controlled by their parent banks' management, this also implies commercial banks' dominant presence in the mutual fund industry.

Banks' dominant position in the mutual fund industry also provides an intuitive explanation on the the fast-pace growth of the mutual fund industry over the past decade. Banks have a strong profit-seeking motive to promote and provide investment products from their subsidiary AMCs as an alternative to or a supplement for their deposit accounts. First, AMCs usually charge fixed-rate fees (e.g. management fees) on the money under their management, and such revenues would ultimately contribute to their parent banks' profits. Second, offering mutual funds as an alternative to deposit accounts helps lighten the burden of interest payments on banks, especially in the environment of low interest rates and flooding liquidity in the years following the global financial crisis.





Note: *Fund management industry includes mutual funds, provident funds, property funds, and infrastructure funds. Sources: SEC and authors' calculations.

Striking the balance between increasing foreign exposures and limiting risks

To understand the *de facto* risk profiles of mutual funds, we consider mutual funds' actual holdings of financial assets. Different classes of financial assets have distinctive risk profiles, both in terms of the likelihoods of states and the exposures to sources of uncertainty. Knowing mutual funds' risk profiles could shed light on the risk transmission channels from the mutual fund industry to systemic risks. Figure 3.16 exhibits the detailed profiles of mutual funds' financial asset holdings. Panel (a) shows the aggregate profile for the entire mutual fund industry, while panels (b) and (c) focus on FIFs and fixed income funds specifically.

For investment in domestic financial assets, the industry-level profile in panel (a) shows that mutual funds continued to invest heavily in NFCs' equities, consistently at around 25 percent of mutual funds' total investment value. Meanwhile, investment in short-term government bonds began to gain more weight in recent years, from 11 percent in January 2015 to 17 percent in June 2018. Other domestic financial assets with a significant share were long-term bonds of FIs, long-term government bonds, and both short- and long-term corporate bonds, all with approximately equal weights. Throughout the years, the evolution of mutual funds' domestic investment remained stable and showed a well-maintained balance between yield enhancements and risk exposures. This is reassured by panel (c), which exhibits a relatively stable proportion of asset holdings of fixed income funds. The only significant change was the replacement of bonds issued by domestic FIs with short-term government bonds. Overall risk levels and exposures due to mutual funds' domestic investment seemed balanced and stable.

An interesting feature at the industry level is on foreign asset holdings. Panel (a) shows that Thai mutual funds continued to put increasing weights on foreign deposits and investment funds. For these two asset classes, their respective shares in total investment value increased from 15 percent and 6 percent in January 2015 to 16 percent and 14 percent in June 2018. Such investment pattern increased the exposures to global financial markets while limiting the associated risks at the same time, because the weights were tilted toward asset classes that were safer and more diversified. A closer look into FIFs' asset holdings in panel (b) also points to the same pattern. Despite the overall increase in foreign market exposures via FIFs, there was a counterbalancing shift toward safer asset classes. This could be seen from the declining shares of short- and long-term bonds of foreign FIs (i.e. the "riskier" assets) and the increasing shares of foreign investment funds and deposits (i.e. the "safer" assets).



Figure 3.16: Detailed profiles of mutual funds' financial asset holdings Breakdown of investment value by asset class



Deposits: global





Sources: SEC and authors' calculations.

3.5 Special discussion: mapping external financial linkages

The Thai financial system has become increasingly integrated with global financial markets. While this has provided tremendous benefits to the domestic financial system, it also inevitably leads to greater contagion risks and exposes domestic sectors to adverse developments in foreign markets. Therefore, it is a much-needed extension to our framework to incorporate more granular information on cross-border exposures, so that realistic transmission mechanisms of external shocks could be captured. As a starting point in this direction, this subsection provides a preliminary overview of Thailand's external financial linkages to highlight some key stylized facts and make this paper's objective of mapping the entire financial landscape more complete. For this purpose, we will use the International Investment Position (IIP) database, which presents Thailand's financial balance sheet vis-à-vis the rest of the world. The IIP database provides a summary of financial interlinkages between Thai residents and non-resident counterparties, with detailed breakdown by resident sector and counterparty country. Note that this presents a further refinement from previous sections, where non-resident counterparties from all countries were bundled as a single Rest of World (ROW) sector. A full-scale inclusion of granular cross-border data will be implemented in the future phase of the project.

Based on the IIP database as of end-2017, Figure 3.17 presents Thailand's external balance sheet with breakdown by resident sector and counterparty country.¹⁷ Figure 3.18 gives a further decomposition by instrument. For each mosaic tile, its size represents the outstanding amount of assets or liabilities as of end-2017, and its color indicates the corresponding resident sector.¹⁸ Taken together, Figures 3.17 and 3.18 give an aggregate-level characterization of Thailand's external balance sheet. With external assets (456.8 USD billion) smaller than external liabilities (488.8 USD billion), Thailand's net IIP at end-2017 was negative, which means that Thailand was a net borrower vis-à-vis the rest of the world. On the asset side (panel (a) in both figures), central bank's international reserves accounted for almost half of external assets.¹⁹ Excluding international reserves, a substantial portion of external assets were Thai NFCs' direct investment in debt securities and equities²⁰ and Thai OFCs' portfolio investment in fund shares and deposits. The top-five countries that Thai resident sectors were most exposed to were Hong Kong, Singapore, the United States, Laos, and China. Among these, the top-three countries were financial centers that played a prominent role in intermediating international capital flows, whereas the other two were related to exposures to specific resident sectors (e.g. Thai banks' loan exposures to Laos and Thai funds' investment in debt securities in China). On the liability side, almost half of external liabilities were direct investment (i.e. inward FDI) in Thai NFCs, mostly in form of equities. Meanwhile, portfolio investment in equities accounted for about one-fourth of external liabilities, while loans accounted for only about 14 percent. Most of external liabilities were highly concentrated in the topfive countries, namely: Japan, Singapore, the United Kingdom, the United States, and Hong Kong. Thai

¹⁷ All results are based on the IIP database obtained as of October 2018. Subsequent revisions might result in some discrepancies with the latest data available on BOT website.

¹⁸ As an example, consider Figure 3.17. On the asset side in panel (a), the orange tile inside Hong Kong's mosaic represents the amount that Thai NFCs invested in or held financial claims on entities that were residents of Hong Kong. In contrast, on the liability side in panel (b), the orange tile inside Hong Kong's mosaic represents the amount that Thai NFCs owed to entities that were residents of Hong Kong, which could represent an external source of funds for Thai NFCs.

¹⁹ This is shown by the large mosaic tile in teal color in Figure 3.17 panel (a), which shows that central bank (CB) is the corresponding resident sector. Country breakdown is not provided for international reserves, thus labelled as "n/a" in Figure 3.18 panel (a).

²⁰ This is shown by the areas of orange tiles in Figure 3.17 panel (a) that overlap with purple and orange tiles in Figure 3.18 panel (a).

NFCs and ODCs (orange and red tiles in Figure 3.17 panel (b)) were the main recipients of external funds.



Figure 3.17: Structure of Thailand's external financial assets and liabilities (2017Q4) Breakdown by resident sector and counterparty country

IIP assets or liabilities. Refer to Section 2.1 for sector abbreviations. Country codes in the figures: China (CN), Hong Kong (HK), Japan (JP), Laos (LA) Singapore (SG), the United Kingdom (UK), and the United States (US). Sources: BOT and authors' calculations.

Figure 3.18: Structure of Thailand's external financial assets and liabilities (2017Q4)



Figure 3.18: Structure of Thailand's external financial assets and liabilities (2017Q4) Breakdown by instrument and counterparty country

Note: Mosaic tile size is proportional to the outstanding amount of assets or liabilities. Mosaic tile color indicates the type of instrument. DI denotes direct investment. PI denotes portfolio investment.

Country codes in the figures: China (CN), Hong Kong (HK), Japan (JP), Laos (LA) Singapore (SG), the United Kingdom (UK), and the United States (US). Sources: BOT and authors' calculations.

Currency and deposits
 Debt (DI)
 Debt (PI)
 Equity (DI)
 Equity (PI)
 Investment fund shares (PI)
 Loans
 Reserves
 Others

NFC

ODC

OFC

ROW



Figure 3.19: External financial assets and liabilities for selected resident sectors (2017Q4) Breakdown by instrument and counterparty country





ODC



OFC



Note: Mosaic tile size is proportional to the outstanding amount of assets or liabilities. Mosaic tile color indicates the type of instrument. DI denotes direct investment. PI denotes portfolio investment. Refer to Section 2.1 for sector abbreviations. Country codes in the figures: China (CN), Hong Kong (HK), Japan (JP), Laos (LA) Singapore (SG), the United Kingdom (UK), and the United States (US). Sources: BOT and authors' calculations. Currency and deposits
Debt (DI)
Debt (PI)
Equity (DI)
Equity (PI)
Investment fund shares (PI)
Loans
Reserves
Others

Figure 3.19 presents the same information as Figure 3.18, but the results are filtered for three selected resident sectors to highlight their key cross-border exposures as of end-2017. (1) For NFCs: The topthree destinations on the asset side were all major financial centers (Hong Kong, Singapore, and the United States). Indeed, most of NFCs' financial assets in Hong Kong were direct equity investment, and this was partly due to the fact that some Thai NFCs used entities in Hong Kong as gateway to mainland China. Several tax-haven destinations (e.g. the Cayman Islands, the British Virgin Islands, and Mauritius) also showed up among the top-20 countries, with the majority of exposures in direct investment in form of equities and debt securities. On the liability side, most exposures were in form of equities, both as direct investment and portfolio investment, while external loans played a noticeable role but to a lesser extent compared to equities. (2) For ODCs: Key asset-side exposures were loans given to Laos and deposits in Hong Kong. On the other hand, key liability-side exposures were with Japan, the United Kingdom, and Hong Kong. (3) For OFCs: On the asset side, three main exposures were highlighted: (i) fund shares incorporated in Luxembourg and Ireland²¹, which were among the top investment fund domiciles globally thanks to conducive legal and tax framework; (ii) deposits that were highly concentrated in a few countries (e.g. Hong Kong, the United Arab Emirates, and Qatar) where banks continued to offer high deposit rates; and (iii) portfolio debt investment in the Chinese bond market. On the liability side, the largest exposures were with Singapore.

In addition to the discussion above based on the snapshot as of end-2017, historical IIP data over the past decade have also been explored. Some quick observations should be made at this point. (1) At the aggregate level, both external assets and liabilities have grown considerably over the past decade, more than one fold since the global financial crisis. Thailand's role has been that of a net borrower visà-vis the rest of the world. (2) OFCs, especially mutual funds, have been playing an increasing role as investors in foreign financial assets, partly due to the popularity of FIFs among investors in the recent years. (3) In terms of diversification, Thai investors have expanded their asset classes and destination countries over the years. However, a high degree of country concentration remains an issue for some segments of the mutual fund industry (e.g. term funds).

²¹ A large portion of this was due to Thai feeder funds' investment in master funds incorporated in Luxembourg and Ireland.

4. Stress testing

In this section we develop a model of balance sheet network and channels of contagion among entities in the Thai financial system. We describe how balance sheets of these entities are connected, and how to determine their market values. We define three channels of contagion and model how shocks are spread through these channels. We introduce two shock amplification effects and describe how they can magnify the losses. Then we combine everything and characterize the conditions of the new balance sheet network and asset prices that emerge after the system has experienced shocks. At the end, we conduct a stress-testing exercise based on two types of shocks, namely industry and reputational shocks, and discuss the results.

4.1 Network of balance sheets

4.1.1 Players

In this section we consider a network of balance sheets among major players, which consist of (i) central bank (CB), (ii) general government (GG), (iii) households (HHs), (iv) non-financial corporations (NFCs), (v) other depository corporations (ODCs), (vi) other financial corporations (OFCs), (vii) other domestic entities or *residual* (RESID), and (viii) foreign entities or *rest of the world* (ROW). NFCs are broken into eight industries: Agro and Food (AGRO), Consumer Products (CONSUMP), Industrials (INDUS), Property and Construction (PROPCON), Resources (RESOURC), Services (SERVICE), Technology (TECH), and other NFCs (OTHER). There are 36 ODCs, which we simply call banks (BANKs). For OFCs, we consider only mutual funds (MFs) grouped by asset management companies (AMCs) and fund policies due to data limitation on other non-bank institutions. Each fund belongs to one of the 23 AMCs and one of the five fund policies based on their primary asset classes as specified in Section 2.2, namely: equity, fixed income (or *bond*), alternative investment, mixed, and other funds. So we have 115 entities that represent mutual funds. The other players, namely CB, GG, HH, RESID and ROW, are not broken into smaller ones, and so we have a total of 164 players or entities in our system. These players are linked together by a network of balance sheets.

4.1.2 Book values

In this financial system we categorize assets into seven types of financial assets and one type of nonfinancial assets. Financial assets have issuers while non-financial assets do not. These financial assets are (i) cash, (ii) debt securities (or *bonds*), (iii) deposits, (iv) equities, (v) investment fund shares (or *funds*), (vi) loans, and (vii) other financial assets. We assume without loss of generality that one unit of each asset type has a *book value* of one baht. Let C_i , B_i , D_i , E_i , F_i , L_i , and O_i denote the numbers of units of cash, bonds, deposits, equities, investment fund shares, loans, and other financial assets, respectively, that are issued by entity *i* at the current time t = 0. These financial assets are held by one or more holders and hence appear on the asset side of the balance sheets of those holders. At the same time, these assets appear on the liability and equity side of the balance sheets of the issuers. However, equities of CB, GG, HH, RESID, and ROW are not held by other entities and thus do not appear in the asset side of any player's balance sheet. Non-financial assets (e.g. land, buildings, machines, etc.) do not have issuers and we denote by n_i the number of units of non-financial assets held by entity *i*. To represent the asset holding network among entities, we denote by c_{ij} , b_{ij} , d_{ij} , e_{ij} , f_{ij} , l_{ij} , and o_{ij} the numbers of units of cash, bonds, deposits, equities, investment fund shares, loans, and other financial assets, respectively, issued by entity i and held by entity j. So the book value of the total assets of entity i is

$$TA_i = \sum_{j=1}^{M} \left[c_{ji} + b_{ji} + d_{ji} + e_{ji} + f_{ji} + l_{ji} + o_{ji} \right] + n_i,$$

and the book value of the total liabilities of entity *i* is

$$TL_{i} = \sum_{j=1}^{M} [c_{ij} + b_{ij} + d_{ij} + l_{ij} + o_{ij}]$$
$$= C_{i} + B_{i} + D_{i} + L_{i} + O_{i}$$

where M = 164 is the number of entities in the system. Observe that investment fund shares are not included in total liabilities as they are similar to equities in the sense that the holders of fund shares have claims on the values of the funds' assets after deducting all the funds' liabilities.

Sometimes it is useful to divide loans into short-term and long-term loans as we allow the holders of short-term loans to discontinue providing loans to their borrowers when they need liquidity, which cannot be done for long-term loans. Let l_{ij}^{ST} and l_{ij}^{LT} denote the numbers of units of short-term and long-term loans, respectively, issued by entity *i* and held by entity *j*. We define \mathbb{N} as the network of balance sheets described by c_{ij} , b_{ij} , d_{ij} , e_{ij} , l_{ij} , o_{ij} and n_i .

In the stress-testing exercise, we make the following assumptions and modify the balance sheets accordingly:

- We assume that all assets sold are bought by other entities (RESID) except equities that are bought by households (HH). RESID contains insurance companies that should find it attractive to invest in assets such as bonds, loans, other financial assets, and non-financial assets at deep-discount prices. Buyers always use cash to pay for the assets bought.
- We assume that HH and RESID have a huge amount of cash, so that they always have enough cash to pay when they buy assets.
- We assume that CB, GG, HH, and RESID have a large amount of non-financial assets, which make their equities huge and hence they never default on their liabilities.

4.1.3 Liquidation values

Liquidation values refer to the total value of assets when an entity liquidates or sells all of its assets. Assume that the assets of type m issued by entity k can be sold to the markets at time t at market prices $p_{k,t}^m$ where $m \in \{c, b, d, e, f, l, o\}$ and c, b, d, e, f, l, o stand for cash, bonds, deposits, equities, funds, loans, and other financial assets, respectively. Let $p_{i,t}^n$ denote the liquidated price of non-financial assets of entity *i*. The total liquidation value of entity *i* at time *t* is given by

$$LIQ_{i,t} = \sum_{k=1}^{M} \left[p_{k,t}^{c} c_{ki} + p_{k,t}^{b} b_{ki} + p_{k,t}^{d} d_{ki} + p_{k,t}^{e} e_{ki} + p_{k,t}^{f} f_{ki} + p_{k,t}^{l} l_{ki} + p_{k,t}^{o} o_{ki} \right] + p_{i,t}^{n} n_{i}.$$

$$(1)$$

When entity *i* liquidates its assets, the holders of claims on the assets of entity *i* receive the values based on the seniority of the claims. We assume that cash is of the highest seniority, while bonds, deposits, loans, and other financial assets all have the second highest seniority. Equities and funds have the lowest and equal seniority. Let $V_{i,t}^m$ denote the total value of claims at time *t* of the holders of asset type *m* issued by entity *i* when entity *i* liquidates its assets. We have:

$$V_{i,t}^c = \min\left\{C_i, \max\left[0, LIQ_i\right]\right\}$$
(cash) (2)

$$V_{i,t}^{b} = B_{i} \times \min\left\{1, \frac{\max\left[0, LIQ_{i} - C_{i}\right]}{B_{i} + D_{i} + L_{i} + O_{i}}\right\}$$
(bond) (3)

$$V_{i,t}^{d} = D_i \times \min\left\{1, \frac{\max\left[0, LIQ_i - C_i\right]}{B_i + D_i + L_i + O_i}\right\}$$
(deposit) (4)

$$V_{i,t}^{l} = L_{i} \times \min\left\{1, \frac{\max\left[0, LIQ_{i} - C_{i}\right]}{B_{i} + D_{i} + L_{i} + O_{i}}\right\}$$
(loan) (5)

$$V_{i,t}^{o} = O_i \times \min\left\{1, \frac{\max\left[0, LIQ_i - C_i\right]}{B_i + D_i + L_i + O_i}\right\}$$
(other) (6)

$$V_{i,t}^{e} = \left(\frac{E_{i}}{E_{i} + F_{i}}\right) \max\left[0, LIQ_{i} - (C_{i} + B_{i} + D_{i} + L_{i} + O_{i})\right]$$
(equity) (7)

$$V_{i,t}^{f} = \left(\frac{F_{i}}{E_{i} + F_{i}}\right) \max\left[0, LIQ_{i} - (C_{i} + B_{i} + D_{i} + L_{i} + O_{i})\right].$$
(fund) (8)

We assume that the value of the claims is distributed to each holder proportional to the par value of the holder. Let $v_{ij,t}^m$ denote the value of the claims of type m at time t issued by entity i that is received by entity j when entity i liquidates its assets. We have for $m \in \{c, b, d, e, f, l, o\}$

$$v_{ij,t}^{m} = \frac{m_{ij}}{\sum_{k=1}^{M} m_{ik}} V_{i,t}^{m}.$$
(9)

If all entities liquidate all of their assets at the same time, we must have

$$p_{i,t}^{m} = \frac{V_{i,t}^{m}}{\sum_{k=1}^{M} m_{ik}}.$$
(10)

In that case we can determine the liquidated values $V_{i,t}^m$ by solving the system of equations (1)-(8) with the condition (10) for all m and i.

4.1.4 Market values

Financial assets are traded at market prices, not at book or liquidation values. Market values of financial assets take into account the risks associated with the realized values of the assets at their maturities or when they are claimed by the holders. To compute the market values of each asset, we use the corporate debt pricing framework based on Merton (1974), which is generalized to account for cross-holdings by

Suzuki (2002) and Fischer (2014). Specifically, we assume that all claims on financial assets are due at time T > 0 and the price of entity *i*'s non-financial assets follows a Geometric Brownian motion, with the price at time T given by

$$p_{iT}^{n} = e^{\left(r - \frac{1}{2}\sigma_{i}^{2}\right)T + \sigma_{i}W_{i,T}}$$
(11)

where r is the constant risk-free rate of return, σ_i is the volatility of return of entity *i*'s non-financial assets, and W_i is a standard Brownian motion under the risk-neutral probability, which can be correlated across entities. Note that the market price of non-financial assets at time 0 is the same as the book value, which is one baht.

Given the non-financial asset prices $p_{i,T}^n$, i = 1, ..., M at the maturity time T, when all entities liquidate their assets, the value of each claim of type m issued by entity i denoted by $V_{i,T}^m$ can be determined from solving (1)-(8) together with (10) with t = T. To compute the current market prices at time 0, we simply simulate the prices of the non-financial assets $\{p_{i,T}^n, i = 1, ..., M\}$ based on (11) and compute the claim values $V_{i,T}^m$. We repeat the simulation many times and compute the average of the discounted value of each $V_{i,T}^m$ to obtain the current market value of the claims:

$$V_{i,0}^m = e^{-rT} \mathbb{E}[V_{i,T}^m].$$
(12)

The current prices are therefore equal to

$$p_{i,0}^{m} = \frac{V_{i,0}^{m}}{\sum_{k=1}^{M} m_{ik}}.$$
(13)

In subsequent sections, we use p_i^m to denote the initial market price of type-*m* assets issued by entity *i* instead of $p_{i,0}^m$.

4.2 Shock transmission channels

There are several channels that transmit shocks from an entity to others. In this paper we consider three channels of shock transmission: the liability and ownership channel, the risk channel, and the market channel. This section describes how we model each of these transmission channels of shocks, which will be used in our stress-testing exercise in Section 4.5.

4.2.1 Liability and ownership channel

The liability and ownership channel is formed by entities holding claims on the assets of one another. When an entity needs liquidity, it may borrow from other entities who act as liquidity providers. Certain forms of liabilities can be withdrawn by the liquidity providers. Deposits, for example, can be withdrawn by the depositors. Short-term loans, when they are due, are subject to rollover risks. When the lenders need liquidity, they can withdraw deposits or reject applications for renewing short-term loans from their borrowers. Similarly, holders of investment fund shares can sell their shares when they need liquidity.

If entity i is hit by a shock representing losses, it will require liquidity to pay for the losses. The entity could sell its assets or withdraw liquidity from other entities. When liquidity of the borrowers has

When the shock size is sufficiently large, the entity could become insolvent and has to liquidate all of its assets and use the proceeds to settle all of its liabilities. In that case, the losses will be transmitted to its creditors who will get paid less than the liabilities' book values, and to its owners who will lose all of their equity stakes in the insolvent entity.

In the stress-testing exercise, we assume that the entity that experiences shocks uses its assets to pay for the losses. It first considers using a portfolio of cash, bonds, deposits, equities, funds, and short-term loans. More precisely, the entity chooses a fraction $s \in [0, 1]$ and uses $s \times m_{ki}$ units of type-m assets issued by entity k to pay for the losses for all $m \in \{c, b, d, e, f, l^{ST}\}$. If the proceeds from using all of those assets are not sufficient to cover all the losses, the troubled entity will then sell a fraction $q \in [0, 1]$ of the numbers of units of long-term loans, other financial assets, and non-financial assets. So, given that the entity needs to cover the losses of size h_i , it would need to use the fractions s and q equal to

$$s = \min\left(1, \inf\left\{\hat{s} \ge 0 : \sum_{k=1}^{M} \left[R_{k}^{c}(\hat{s}c_{ki}) + R_{k}^{d}(\hat{s}d_{ki}) + R_{k}^{l^{ST}}(\hat{s}l_{ki}^{ST}) + R_{k}^{b}(\hat{s}b_{ki}) + R_{k}^{e}(\hat{s}e_{ki}) + R_{k}^{f}(\hat{s}f_{ki})\right] \ge h_{i}\right\}\right)$$

$$(14)$$

and

$$q = \min\left(1, \inf\left\{\hat{q} \ge 0 : \sum_{k=1}^{M} \left[R_{k}^{c}(c_{ki}) + R_{k}^{d}(d_{ki}) + R_{k}^{l^{ST}}(l_{ki}^{ST}) + R_{k}^{b}(b_{ki}) + R_{k}^{e}(e_{ki}) + R_{k}^{f}(f_{ki}) + R_{k}^{l^{LT}}(\hat{q}l_{ki}^{LT}) + R_{k}^{o}(\hat{q}o_{ki}) + R_{k}^{n}(\hat{q}n_{ki})\right] \ge h_{i}\right\}\right).$$
(15)

4.2.2 Risk channel

Prices of financial claims should reflect the risks of losses. A drop in the asset value of entity *i* reduces the ability of entity *i* to pay back its liabilities to its lenders, as well as reduces the values of equities and funds to their respective holders. If entity *i* is hit by a shock representing losses, and the shock size is not large enough, the entity may remain solvent but the equity value will drop, which increases insolvency risks and as a result lowers the values of the claims on entity *i*'s assets. This type of losses is transmitted to other entities who hold claims on the assets of entity *i*. In the stress-testing exercise, we reprice the market values of assets based on the method described in Section 4.1.4.

4.2.3 Market liquidity channel

When entities hold the same assets, they are exposed to the same price risks. A large sell of assets by one entity may push asset prices down as the markets do not have sufficient liquidity to absorb the selling at current market prices. Consequently, the sellers have to sell the assets at *fire-sale* prices. Other

entities holding the same assets will also experience the reduction in the value of their assets and hence their equities. We model fire-sale prices using inverse demand functions. Specifically, let p_i^m denote the initial market price of type-*m* assets issued by entity *i*, and U_i^m the initial number of units of type-*m* assets. For assets that are relatively more liquid such as bonds and equities, we assume that a sell of *u* units of the assets reduces the price to

$$p_i^m(u) = p_i^m e^{-\alpha_i^m u/U_i^m}, \qquad m = b, e$$
 (16)

where $\alpha_i^m \ge 0$ denotes the price liquidity parameter: the larger the value of α_i^m , the larger the fire-sale effects. This type of inverse demand functions is commonly used in the literature. See Cifuentes, Ferrucci, and Shin (2005) for example. For relatively less liquid assets such as long-term loans, other financial assets, and non-financial assets, we assume that the fire-sale price from selling u units is represented by a constant percentage discount:

$$p_i^m(u) = \begin{cases} p_i^m & \text{if } u = 0\\ \beta_i^m p_i^m & \text{if } u > 0 \end{cases}, \qquad m = l^{LT}, o, n$$
(17)

where $0 \le \beta_i^m \le 1$ is the fraction of the current price received when selling these low-liquidity assets. We assume that cash is perfectly liquid, while deposits and short-term loans can be withdrawn at their face values given that the borrowers are able to repay in full. For fund redemption, the unitholders receive the value of the fund based on the fund value per unit. Note that when funds are redeemed, the funds have to sell assets at fire-sale prices, which will then lower the fund values.

Finally, we summarize the proceeds received from selling assets of each type. Let $R_i^m(u)$ denote the proceed received when u units of type-m assets issued (held, for m = n) by entity i are sold or withdrawn. We have:

$$R_i^m(u) = u, m = c, d, l^{ST} (18)$$

$$R_i^m(u) = p_i^m u, \qquad m = f \tag{19}$$

$$R_i^m(u) = \int_0^u p_i^m(v) dv = \frac{p_i^m U_i^m}{\alpha_i^m} (1 - e^{-\alpha_i^m u/U_i^m}), \qquad m = b, e$$
(20)

$$R_i^m(u) = \beta_i^m p_i^m u,$$
 $m = l^{LT}, o, n.$ (21)

4.3 Amplification effects

There are many effects that might amplify shocks, which in turn could make the damages much larger than what the original shocks would have caused. We consider two types of amplification effects: panic selling and bank deleveraging effects. This section describes the shock amplification mechanisms of the two effects.

4.3.1 Panic selling

Uninformed investors are likely to learn from asset prices, as they do not observe the underlying factors driving asset values. Once they see significant decreases in asset prices, they are likely to infer that informed investors have sold the assets due to some negative information that they themselves cannot

observe, and hence start to sell their assets. This behavior, which is known as *panic selling*, could amplify the effects of shocks dramatically. The entity that experiences large losses sells a huge amount of assets to raise enough liquidity to pay for the losses, which in turn pushes the asset prices down, which then triggers uninformed investors to further sell the assets due to panic, reinforcing the fire-sale effects in the markets. Entities that hold such assets, though are not hit directly by shocks, lose their equity values and this could trigger defaults of some high leveraged entities.

In the stress-testing exercise, we assume that households, at the aggregate level, act as uninformed investors who will sell bonds, stocks, and investment fund shares after observing price drops. Let $x_i^m(\Delta p)$ denote the percentage of their holdings in assets of type m issued by entity i to be sold when they observe a drop of Δp in p_i^m . We assume the following linear panic selling function with a maximum level:

$$x_i^m(\Delta p) = \min(X_i^m, \max\{0, \gamma_i^m \Delta p\})$$
(22)

where X_i^m represents the maximum fraction of assets sold due to panic and γ_i^m is the panic sensitivity parameter: the higher the value of γ_i^m , the larger sell made due to panic.

4.3.2 Bank deleveraging

Banks tend to maintain their leverage ratios, as defined by the ratio of total liability to equity, at their targets. When they experience losses that reduce their equity values, they will *deleverage* either by selling their assets to pay back their liabilities or by raising their capitals. However, during the bad times, it is difficult to raise capitals and selling assets might be an easier, though undesirable, way to bring the leverage ratios back to their targets. In the process of selling assets, banks normally discontinue giving short-term loans, causing liquidity reduction for their borrowers who, as a result, need to raise liquidity to pay back the loans by selling their assets at possibly deep discount prices, which further amplify the effects of shocks. Greenwood, Landier, and Thesmar (2015) and Tressel (2010) assume that banks deleverage in their studies.

Let LR_i denote the leverage ratio of bank i, and $\overline{LR_i}$ its target leverage ratio. Also, let EV_i and TL_i denote the equity value and total liability, respectively, of entity i. When $LR_i > \overline{LR_i}$, we assume that bank i pays back its deposits to the depositors so that LR_i is as close to $\overline{LR_i}$ as possible. That is, the bank requires to reduce the deposit liability by a magnitude of

$$\Delta D_i = \min(D_i, TL_i - \overline{RL}_i \times EV_i).$$
⁽²³⁾

Although it may sound unusual for banks to pay their deposits back to the depositors, banks do have certain control over their deposits through the control of deposit rates: banks could lower the deposit rates to reduce the size of deposits. An alternative explanation for the reduction in the deposits could be that depositors withdraw their deposits at their own will from banks with higher-than-expected leverage ratios, and the withdrawal continues until banks' leverage ratios go back down to their target values.

To raise cash for paying their depositors, we assume that banks do that in the same manner as described by (14)-(15). Finally, we assume that if banks have leverage ratios above a threshold LR_{max} set by the regulator, they are forced to liquidate all of their assets and go out of business due to unacceptably high

risks.

4.4 Equilibrium values

In our setup, once a shock hits an entity, it can be transmitted to other entities through the three channels as described above. There are two major types of outcomes after the shock is realized: (i) the whole financial system collapses and there are no asset prices; or (ii) the system manages to survive the losses and reaches a new equilibrium where the network of balance sheets and the asset prices may change dramatically. In this section, we characterize the resulting balance sheet network and asset prices when the system survives from the shock.

Recall that initially entity *i* holds m_{ki} units of type-*m* assets issued by entity *k* for $m \in \{c, b, d, e, f, l^{ST}, l^{LT}, o\}$ and n_i units of non-financial assets. The initial price of type-*m* assets issued by entity *k* is p_k^m and the price of non-financial assets of entity *i* is p_i^n . Let \tilde{m}_{ki} and \tilde{p}_k^m denote the number of units held by entity *i* and the price of type-*m* assets issued by entity *k* after the shock is realized by the entire system. Similarly, let \tilde{n}_i and \tilde{p}_i^n denote the after-shock number of units and the price of non-financial assets of entity *i*. The goal in this section is to determine \tilde{m}_{ki} and \tilde{p}_k^m , as well as \tilde{n}_i and \tilde{p}_i^n , among other quantities, that characterize the financial system at the new equilibrium. We use the notation *tilde* (\cdot) to represent the values at the new equilibrium.

We need to include all the shock transmission channels and amplification effects into consideration when we derive the conditions at the new equilibrium. Let $\widetilde{\mathbb{N}}$ denote the balance sheet network at the new equilibrium. Also, denote by $\Delta_j^S m_{ki}$ and $\Delta^W m_{ki}$ the changes (in magnitude) in the numbers of units of type-*m* assets issued by entity *k* and held by entity *i* due to entity *i selling* the assets to entity *j*, and due to entity *i withdrawing/redeeming* the assets from entity *k*, respectively. Similarly, let $\Delta_k^S n_i$ and $\Delta^R d_{ki}$ denote the number of units of non-financial assets that entity *i sells* to entity *k* and the number of deposit units that bank *k* chooses to *return* to its depositor *i* in the deleveraging process. We first characterize the conditions of the numbers of units of assets at the new equilibrium in (24)-(28).

$$\tilde{c}_{ki} = \begin{cases} c_{ki} + In_i - Out_i & \text{if } k = CB \\ 0 & \text{else} \end{cases}$$
(24)

$$\tilde{d}_{ki} = d_{ki} - \Delta^W d_{ki} - \Delta^R d_{ki}$$
(25)

$$\tilde{m}_{ki} = m_{ki} + \sum_{j=1}^{M} \Delta_i^S m_{kj} - \sum_{j=1}^{M} \Delta_j^S m_{ki}, \qquad m = b, e, l^{LT}, o$$
(26)

$$\tilde{m}_{ki} = m_{ki} - \Delta^W m_{ki}, \qquad m = f, l^{ST}$$
(27)

$$\tilde{n}_{i} = n_{i} + \sum_{j=1}^{M} \Delta_{i}^{S} n_{j} - \sum_{j=1}^{M} \Delta_{j}^{S} n_{i}.$$
(28)

The number of units of cash held by entity *i* at the new equilibrium is given by (24). We assume that only the central bank (CB) issues cash in our system. The changes in the number of units of cash come from the cash inflows to entity *i* or In_i and the cash outflows from entity *i* or Out_i . We provide more specific details about these two quantities in (38)-(39) below. The number of units of deposits issued by entity *k* to depositor *i* is given in (25), which is equal to the initial units minus the number of deposit units that

depositor *i* withdraws from entity *k* and the number of deposit units entity *k* returns to depositor *i*. The numbers of units of bonds, equities, long-term loans, and other financial assets are given in (26). The changes in the numbers of units held by entity *i* come from other entities selling the assets to entity *i* and entity *i* selling the assets to other entities. For funds and short-term loans, the changes in the numbers of units come from fund redemption and discontinuity of short-term loan rollover. Similar to (26), (28) describes the changes in the number of non-financial assets held by entity *i*, which come from entity *i* buying (selling) non-financial assets from (to) other entities. Note that we assume that non-financial assets, once changing hands, will be relabeled as non-financial assets of the new owner.

Before we move on to the next set of new equilibrium conditions, we denote by $\Delta^S b_k$ and $\Delta^S e_k$ the numbers of total units of bonds and equities issued by entity k that are sold into the markets, respectively:

$$\Delta^S b_k = \sum_{j=1}^M \sum_{i=1}^M \Delta_j^S b_{ki} \tag{29}$$

$$\Delta^S e_k = \sum_{j=1}^M \sum_{i=1}^M \Delta_j^S e_{ki}.$$
(30)

The next set of conditions is for the new equilibrium prices:

$$\tilde{p}_k^m = \hat{p}_k^m(\widetilde{\mathbb{N}}), \qquad \qquad m = c, d, l, o, n \tag{31}$$

$$\tilde{p}_{k}^{b} = \hat{p}_{k}^{b}(\widetilde{\mathbb{N}}) \exp\left\{-\alpha_{k}^{b} \frac{\Delta^{S} b_{k}}{B_{k}}\right\}$$
(32)

$$\tilde{p}_{k}^{e} = \hat{p}_{k}^{e}(\widetilde{\mathbb{N}}) \exp\left\{-\alpha_{k}^{e} \frac{\Delta^{S} e_{k}}{E_{k}}\right\}$$
(33)

$$\tilde{p}_k^f = \frac{F_k}{E_k + F_k} \widetilde{EV}_k. \tag{34}$$

Prices of all assets, except funds, are directly subject to insolvency risks and cross-holdings among entities as summarized by the new network of balance sheets $\widetilde{\mathbb{N}}$. The prices are denoted by \hat{p} , which can be computed as in Section 4.1.4 based on the new balance sheet network $\widetilde{\mathbb{N}}$. Only bonds and equities are directly subject to the fire-sale effects, which depend on the total number of units sold to the markets, as shown by the exponential term in (32)-(33). Prices of investment fund shares, on the other hand, depend on the equity values of the funds or \widetilde{EV} , which are indirectly affected by the network of balance sheets and the fire-sale effects through asset holdings of the funds. The equity value of an entity is computed from its total assets minus its total liabilities. The total asset value is computed based on the market value while the total liability value is computed based on the book value. More specifically, let \widetilde{TA}_i and \widetilde{TL}_i denote the total assets and total liabilities of entity *i*. We have:

$$\widetilde{TA}_{i} = \sum_{k=1}^{M} \left[\tilde{c}_{ki} \tilde{p}_{k}^{c} + \tilde{b}_{ki} \tilde{p}_{k}^{b} + \tilde{d}_{ki} \tilde{p}_{k}^{d} + \tilde{e}_{ki} \tilde{p}_{k}^{e} + \tilde{f}_{ki} \tilde{p}_{k}^{f} + \tilde{l}_{ki} \tilde{p}_{k}^{l} + \tilde{o}_{ki} \tilde{p}_{k}^{o} \right] + \tilde{n}_{i} \tilde{p}_{i}^{n}$$
(35)

$$\widetilde{TL}_{i} = \sum_{k=1}^{M} \left[\tilde{c}_{ik} + \tilde{b}_{ik} + \tilde{d}_{ik} + \tilde{l}_{ik} + \tilde{o}_{ik} \right]$$
(36)

$$\widetilde{EV}_i = \widetilde{TA}_i - \widetilde{TL}_i. \tag{37}$$

Now we focus on the flows of cash. Let \tilde{r}_{ki}^m denote the amount of cash (revenue) entity *i* receives from having type-*m* assets issued by entity *k*. This cash may come from entity *i* selling the assets, withdrawing deposits (including receiving back the deposits due to bank deleveraging), redeeming investment fund shares, discontinuing short-term loans, and receiving liquidation values of defaulted entities. Similarly, let \tilde{r}_i^n denote the cash received by entity *i* from selling its non-financial assets. The total cash inflows of entity *i* is therefore:

$$In_{i} = \sum_{k=1}^{M} \left[\tilde{r}_{ki}^{b} + \tilde{r}_{ki}^{d} + \tilde{r}_{ki}^{e} + \tilde{r}_{ki}^{f} + \tilde{r}_{ki}^{l^{ST}} + \tilde{r}_{ki}^{l^{LT}} + \tilde{r}_{ki}^{o} \right] + \tilde{r}_{i}^{n}.$$
(38)

On the other hand, the cash outflows of entity *i* consist of losses from external shocks (h_i), withdrawal of deposits by the depositors, return of deposits to the depositors (deleveraging process), redemption of fund shares by the investors, stopping giving short-term loans by the lenders, and cash paid to buy assets:

$$Out_{i} = h_{i} + \sum_{j=1}^{M} \left[\Delta^{W} d_{ij} + \Delta^{R} d_{ij} + \Delta^{W} f_{ij} \tilde{p}_{i}^{f} + \Delta^{W} l_{ij}^{ST} \right]$$

+ $\mathbf{1}_{\{i=HH,DF_{i}=0\}} \sum_{j=1}^{M} \tilde{r}_{ij}^{e} + \mathbf{1}_{\{i=RESID,DF_{i}=0\}} \sum_{j=1}^{M} \left[\tilde{r}_{ij}^{b} + \tilde{r}_{ij}^{l^{T}} + \tilde{r}_{ij}^{o} + \tilde{r}_{j}^{n} \right]$
+ $\mathbf{1}_{\{DF_{i}=1\}} \sum_{j=1}^{M} \left[\tilde{r}_{ij}^{b} + \tilde{r}_{ij}^{d} + \tilde{r}_{ij}^{l^{ST}} + \tilde{r}_{ij}^{l^{TT}} + \tilde{r}_{ij}^{o} \right]$ (39)

where DF_i denotes the default variable of entity *i* which takes value 1 if entity *i* defaults and 0 otherwise. As we can see, in case of default, the outflows represent the liquidation values paid to all the lenders, as included in \tilde{r} terms, which is explained below. There are three cases that an entity can default. More specifically, entity *i* defaults if at least one of the following conditions is met:

- Entity *i* is insolvent: $\widetilde{EV}_i < 0$.
- Entity *i* does not have enough liquidity: $\sum_{k=1}^{M} \tilde{c}_{ki} < 0$.
- Entity *i* is a bank and it fails to meet the leverage ratio condition set by the regulator: $\widetilde{TL}_i/\widetilde{EV}_i > LR_{max}$.

To determine the proceeds received by each entity, let \widetilde{R}_k^m denote the total proceeds from selling assets of type m issued by entity k for m = b, e, f. These proceeds will be divided among all the sellers proportional to the number of units sold by each seller. We have:

$$\widetilde{R}_k^b = \frac{p_k^m B_k}{\alpha_k^b} (1 - e^{-\alpha_k^b \Delta^S b_k / B_k})$$
(40)

$$\widetilde{R}_{k}^{e} = \frac{p_{k}^{m} E_{k}}{\alpha_{k}^{e}} (1 - e^{-\alpha_{k}^{e} \Delta^{S} e_{k}/E_{k}})$$
(41)

$$\widetilde{R}_k^f = \widetilde{p}_k^f \Delta^W f_k.$$
(42)

First consider the revenues that entity *i* receives from bonds, equities, and funds issued by entity *k* or \tilde{r}_{ki}^m for m = b, e, f which are given by:

$$\tilde{r}_{ki}^{b} = \begin{cases} \min\left\{1, \frac{\max\left[0, \widetilde{LIQ}_{k} - C_{k}\right]}{B_{k} + D_{k} + L_{k} + O_{k}}\right\} b_{ki} & \text{if } DF_{k} = 1\\ (\tilde{s}_{i} + \tilde{x}_{i}(1 - \tilde{s}_{i})) b_{ki} \times \frac{\widetilde{R}_{k}^{b}}{\Delta^{S} b_{k}} & \text{else} \end{cases}$$

$$(43)$$

$$\tilde{r}_{ki}^{e} = \begin{cases} \frac{\max\left[0, \widetilde{LIQ}_{k} - (C_{k} + B_{k} + D_{k} + L_{k} + O_{k})\right]}{E_{k} + F_{k}} & \text{if } DF_{k} = 1\\ (\tilde{s}_{i} + \tilde{x}_{i}(1 - \tilde{s}_{i})) e_{ki} \times \frac{\widetilde{R}_{k}^{e}}{\Delta^{S} e_{k}} & \text{else} \end{cases}$$

$$(44)$$

$$\tilde{r}_{ki}^{f} = \begin{cases} \frac{\max\left[0, \widetilde{LIQ}_{k} - (C_{k} + B_{k} + D_{k} + L_{k} + O_{k})\right]}{E_{k} + F_{k}} & \text{if } DF_{k} = 1\\ (\tilde{s}_{i} + \tilde{x}_{i}(1 - \tilde{s}_{i})) f_{ki} \times \tilde{p}_{k}^{f} & \text{else} \end{cases}$$

$$(45)$$

where \widetilde{LIQ}_k is the liquidation value of entity k and \tilde{s}_i is the fraction of the numbers of units of bonds, equities, and funds sold by entity i which, if i = HH, happens before panic selling. The fraction of units sold due to panic is \tilde{x}_i , which is the fraction of the remaining units after selling \tilde{s}_i of the total units. As we can see, the revenue is the portion of the liquidated value of entity k that entity i can claim if entity k defaults, and is the proceed from selling the assets if entity k does not default.

Now consider the cash inflows from deposits and short-term loans. We have:

$$\tilde{r}_{ki}^{d} = \begin{cases} \min\left\{1, \frac{\max\left[0, \widetilde{LIQ}_{k} - C_{k}\right]}{B_{k} + D_{k} + L_{k} + O_{k}}\right\} d_{ki} & \text{if } DF_{k} = 1\\ \tilde{s}_{i}(d_{ki} - \Delta^{R}d_{ki}) + \Delta^{R}d_{ki} & \text{else} \end{cases}$$

$$(46)$$

$$\tilde{r}_{ki}^{l^{ST}} = \begin{cases} \min\left\{1, \frac{\max\left[0, \widetilde{LIQ}_k - C_k\right]}{B_k + D_k + L_k + O_k}\right\} l_{ki}^{ST} & \text{if } DF_k = 1\\ \\ \tilde{s}_i l_{ki}^{ST} & \text{else} \end{cases}$$

$$(47)$$

The cash inflows of entity *i* from deposits come from the receipt of returned deposits due to deleveraging $(\Delta^R d_{ki})$, and the withdrawal of deposits as the fraction \tilde{s}_i of the remaining number of units of deposits. The cash inflows from short-term loans come from discontinuing giving short-term loans. When entity

k, the borrower, defaults, the cash inflows are the portions of the liquidated value that entity i can claim.

For cash inflows from long-term loans, other financial assets, and non-financial assets, they are proceeds from sales or the portion of the liquidated values if the issuers of long-term loans or other financial assets default. That is,

$$\tilde{r}_{ki}^{l^{LT}} = \begin{cases} \min\left\{1, \frac{\max\left[0, \widetilde{LIQ}_k - C_k\right]}{B_k + D_k + L_k + O_k}\right\} l_{ki}^{LT} & \text{if } DF_k = 1\\ \\ \tilde{q}_i l_{ki}^{LT} \times \beta_k^{l^{LT}} \tilde{p}_k^{l^{LT}} & \text{else} \end{cases}$$
(48)

$$\tilde{r}_{ki}^{o} = \begin{cases} \min\left\{1, \frac{\max\left[0, \widetilde{LIQ}_{k} - C_{k}\right]}{B_{k} + D_{k} + L_{k} + O_{k}}\right\} o_{ki} & \text{if } DF_{k} = 1\\ \tilde{q}_{i}o_{ki} \times \beta_{k}^{o}\tilde{p}_{k}^{o} & \text{else} \end{cases}$$

$$(49)$$

$$\tilde{r}_i^n = \tilde{q}_i n_i \times \beta_i^n \tilde{p}_i^n \tag{50}$$

where \tilde{q}_i is the fraction of the total number of units of long-term loans, other financial assets, and nonfinancial assets sold. Note that selling these assets is subject to a discount fraction of $1 - \beta_k^m$, which represents the effects of fire sales.

To define the liquidation value \widetilde{LIQ}_k , let $\hat{r}_{ki}^m(\hat{s})$ denote the value of \tilde{r}_{ki}^m defined by (43)-(47) with \tilde{s}_i replaced by \hat{s} , $\hat{r}_{ki}^m(\hat{q})$ the value of \tilde{r}_{ki}^m defined by (48)-(49) with \tilde{q}_i replaced by \hat{q} , and $\hat{r}_i^n(\hat{q})$ the value of \tilde{r}_i^n defined by (50) with \tilde{q}_i replaced by \hat{q} . We have:

$$\widetilde{LIQ}_{k} = \sum_{j=1}^{M} \left[c_{jk} + \hat{r}_{jk}^{b}(1) + \hat{r}_{jk}^{d}(1) + \hat{r}_{jk}^{e}(1) + \hat{r}_{jk}^{f}(1) + \hat{r}_{jk}^{l^{ST}}(1) + \hat{r}_{jk}^{l^{LT}}(1) + \hat{r}_{jk}^{o}(1) \right] + \hat{r}_{k}^{n}(1).$$
(51)

That is, \widetilde{LIQ}_k is the total proceeds from selling all of the assets of entity k.

We next determine the fraction of assets sold to cover liquidity needs of entity *i*:

$$\tilde{s}_{i} = \min\left(1, \inf\left\{\hat{s} \ge 0: \sum_{k=1}^{M} \hat{s}(c_{ki} + In_{ki}) + \sum_{k=1}^{M} \left(\hat{r}_{ki}^{b}(\hat{s}) + \hat{r}_{ki}^{d}(\hat{s}) + \hat{r}_{ki}^{e}(\hat{s}) + \hat{r}_{ki}^{f}(\hat{s}) + \hat{r}_{ki}^{I^{ST}}(\hat{s})\right) \mathbf{1}_{\{DF_{k}=0\}} \ge Out_{i}\right\}\right)$$

$$\tilde{q}_{i} = \min\left(1, \inf\left\{\hat{q} \ge 0: \sum_{k=1}^{M} (c_{ki} + In_{ki}) + \sum_{k=1}^{M} (\hat{r}_{ki}^{b}(1) + \hat{r}_{ki}^{d}(1) + \hat{r}_{ki}^{e}(1) + \hat{r}_{ki}^{f}(1) + \hat{r}_{ki}^{I^{ST}}(1)\right) \mathbf{1}_{\{DF_{k}=0\}} + \sum_{k=1}^{M} (\hat{r}_{k}^{I^{TT}}(\hat{q}) + \hat{r}_{k}^{o}(\hat{q}) + \hat{r}_{k}^{n}(\hat{q})) \mathbf{1}_{\{DF_{k}=0\}} + \sum_{k=1}^{M} Out_{i} \right\}\right)$$
(52)
$$\tilde{s}_{i} = \min\left(1, \inf\left\{\hat{s} \ge 0: \sum_{k=1}^{M} (c_{ki} + In_{ki}) + \hat{s}_{ki}^{e}(1) + \hat{s}_{ki}^{f}(1) + \hat{s}_{ki}^{I^{ST}}(1)\right) \mathbf{1}_{\{DF_{k}=0\}} + \sum_{k=1}^{M} O(\hat{r}_{k}^{I^{TT}}(\hat{q}) + \hat{r}_{k}^{o}(\hat{q}) + \hat{r}_{k}^{n}(\hat{q})\right) \mathbf{1}_{\{DF_{k}=0\}} \\ \ge Out_{i} \right\}\right)$$
(52)

where

$$In_{ki} = \hat{r}_{ki}^{b}(0) + \hat{r}_{ki}^{d}(0) + \hat{r}_{ki}^{e}(0) + \hat{r}_{ki}^{f}(0) + \hat{r}_{ki}^{l^{ST}}(0) + \hat{r}_{ki}^{l^{LT}}(0) + \hat{r}_{ki}^{o}(0)$$
(54)

is the cash inflows of entity *i* if entity *k* defaults, and zero otherwise. Note that the fraction \tilde{s}_i of cash from entity *i* used to cover liquidity needs of entity *i* is computed from cash including all the proceeds received from all of its defaulted borrowers.

Households are subject to panic selling of bonds, equities, and funds. The fractions of units of those assets sold due to panic are given by

$$\tilde{x}_{i} = \begin{cases} \min \left\{ X_{i}^{m}, \max[0, \gamma_{i}^{m}(p_{i}^{m} - \tilde{p}_{i}^{m})] \right\} & \text{if } i = HH \\ 0 & \text{else} \end{cases}$$
(55)

for m = b, e, f.

Finally, we provide the numbers of units sold:

$$\Delta_{j}^{S}b_{ki} = \begin{cases} \tilde{s}_{i}b_{ki} + \tilde{x}_{i}(1 - \tilde{s}_{i})b_{ki} & \text{if } j = RESID, i = HH \\ \tilde{s}_{i}b_{ki} & \text{if } j = RESID, i \neq HH \\ 0 & \text{else} \end{cases}$$
(56)

$$\Delta_{j}^{S} e_{ki} = \begin{cases} \tilde{s}_{i} e_{ki} + \tilde{x}_{i} (1 - \tilde{s}_{i}) e_{ki} & \text{if } j = HH, i = HH \\ \tilde{s}_{i} e_{ki} & \text{if } j = HH, i \neq HH \\ 0 & \text{else} \end{cases}$$
(57)

$$\Delta_j^S l_{ki}^{LT} = \begin{cases} \tilde{q}_i l_{ki}^{LT} & \text{if } j = RESID\\ 0 & \text{else} \end{cases}$$
(58)

$$\Delta_j^S o_{ki} = \begin{cases} \tilde{q}_i o_{ki} & \text{if } j = RESID \\ 0 & \text{else} \end{cases}$$
(59)

$$\Delta_j^S n_i = \begin{cases} \tilde{q}_i n_i & \text{if } j = RESID\\ 0 & \text{else} \end{cases}, \tag{60}$$

the numbers of units withdrawn/redeemed/discontinued:

$$\Delta^W d_{ki} = \tilde{s}_i d_{ki} \tag{61}$$

$$\Delta^{W} f_{ki} = \begin{cases} \tilde{s}_{i} f_{ki} + \tilde{x}_{i} (1 - \tilde{s}_{i}) f_{ki} & \text{if } i = HH \\ 0 & \text{else} \end{cases}$$
(62)

$$\Delta^W l_{ki}^{ST} = \tilde{s}_i l_{ki}^{ST},\tag{63}$$

and the number of deposit units returned to the depositors:

$$\Delta^{R} d_{ki} = \begin{cases} \frac{d_{ki}}{D_{k}} \min(D_{k}, \widetilde{TL}_{k} - \overline{LR}_{k} \times \widetilde{EV}_{k}) & \text{if } k \text{ is a bank} \\ 0 & \text{else} \end{cases}$$
(64)

A solution to the complex system of equations (24)-(64) determines an equilibrium of the new system given the shocks. In the stress-testing exercise, we update the variables in the system by going through the list of all entities several rounds. The variables should converge to a solution as the number of rounds becomes sufficiently large. Due to high computational demand, we use ten rounds to iterate through all these quantities.

4.5 Stress-testing exercises

In this section, we conduct stress testing on the Thai financial system based on the model developed in the previous section. We first describe our parameters. Then we apply two types of shocks and study the stability of the financial system.

4.5.1 Parameters

There are many parameters needed in our model. To price the value of each item in the balance sheets associated with insolvency risks and cross-holdings, we set the maturity date T = 1 year and the interest

rate r = 1 percent. We estimate the volatility of the log-returns on non-financial assets based on the returns of industry indices in the Stock Exchange of Thailand. More precisely, we use the monthly total index returns of each industry over 2008-2017 to compute the annualized volatilities of log-returns, and round them to the nearest 5 percent. We set the value of volatility of non-financial assets of each industry to its respective number, and set that of OTHER, banks, and funds to the average number across all industries. Although the estimates are obtained from equity values, not asset values, the relative size of the estimates should capture the different risk levels of non-financial assets, which are the major parts of business risks in these non-financial industries. We assume a low volatility of 10 percent for CB, GG, HH, RESID and ROW. All non-financial asset returns are assumed to be independent. Table 4.1 summarizes these parameters.

Table 4.1: Market value parameters

This table provides the values of the parameters used to compute market values as described in Section 4.1.4. The volatilities of NFC industries are estimated from monthly data of respective industry indices and are rounded to the nearest 5 percent. The average number is used for OTHER, banks, and funds. We assume a low volatility of 10 percent for the rest. All non-financial asset returns are assumed to be independent.

Interest	Horizon	Annualized volatility							
rate	(T)	(σ_i)							
(r)		CB, GG, HH,	OTHER,	AGRO, TECH,	CONSUMP	INDUS	PROPCON,		
		RESID, ROW	BANK, MF	SERVICE			RESOURC		
1%	1 year	10%	22%	20%	15%	30%	25%		

Note: Refer to the beginning of Section 4.1 for abbreviations. Source: Authors' calculations.

In the fire-sale function (16), we require the liquidity parameters of bonds and equities. We use estimates from SEC for bonds, and estimate the liquidity of stock markets by using the price index return of the SET index during 2008. We compute the turnover of the market as the total value traded in 2008 over the market capitalization at the end of year 2007, and compute the annual return in 2008. The turnover in 2008 was approximately 1.20 and the market was down around 47.56 percent. This gives the value of α equal to 0.5380. For the discount parameter in (17), we simply assume a 20 percent discount. Table 4.2 provides the numbers of the parameters for the fire-sale functions.

There are two parameters for the panic selling function (22) for each asset type. We assume that the maximum panic selling is 30 percent for all asset types. The sensitivity parameter γ for bonds and bond funds is assumed to be 5 to represent a 5 percent panic selling when the bond price drops by 1 percent. We estimate this sensitivity parameter for equities using the price index return of the SET index in September 2008. The turnover in that month was around 9.38 percent and the index was down around 12.84 percent. This gives us the value of γ equal to 0.73. We use this parameters for equities and equity funds. For alternative, mixed and other funds, we use $\gamma = 1$ which is between 0.73 for equities and 5 for bonds. We summarize the parameters for the panic function in Table 4.3.

Finally we set the maximum leverage ratio for banks at 15, which is a reasonable bound given the current level of Thai banks' leverage ratios.

Table 4.2: Fire-sale parameters

This table provides the values of the parameters in the fire-sale functions given by (16)-(17). The values of α for bonds are estimated from the SEC and the value of α for equities is estimated based on the SET index price returns during 2008. The values of β are assumed by the authors.

Asset type	Entity	Liquidity	Discount	Interpretation
(m)	(i)	(α_i^m)	(β_i^m)	·
Bonds	CB, GG, ROW	0.1675	-	price drops 1% for 6% sold
Bonds	NFC, RESID, BANK	0.2519		price drops 1.5% for 6% sold
Equities	ALL	0.5380		price drops 5.24% for 10% sold
Long-term loans	ALL		0.8	a discount of 20% for every sell
Other financial assets	ALL		0.8	a discount of 20% for every sell
Non-financial assets	ALL		0.8	a discount of 20% for every sell

Note: Refer to the beginning of Section 4.1 for abbreviations. Source: Authors' calculations.

Table 4.3: Panic selling parameters

This table provides the values of the parameters in the panic selling function given by (22). The values of γ for equities and equity funds are estimated based on the SET index return during September 2008. The values of other γ and X are assumed by the authors.

Asset type	Entity	Max selling	Sensitivity	Interpretation
(m)	(i)	(X_i^m)	(γ_i^m)	
Bonds and bond funds	ALL	0.3	5.00	sell 1% if price drops 20 bps
Equities and equity funds	ALL	0.3	0.73	sell 7.3% if price drops 10%
Alternative/mixed/other funds	ALL	0.3	1.00	sell 1% if price drops 1%

Source: Authors' calculations.

4.5.2 Incremental effects of shocks

In our paper shocks from one entity can spread to other entities through three channels of contagion, and the effects of shocks could be amplified by panic selling and bank deleveraging. To measure the incremental effects on each component of the model, we stress test five different model specifications:

- (i) Model A: model with the liability and ownership channel
- (ii) Model B: Model A with the risk channel
- (iii) Model C: Model B with the market channel
- (iv) Model D: Model C with panic selling
- (v) Model E: Model D with bank deleveraging

Model A is our base case that allows players to act based on financial agreements through the borrowing and lending relationship, and the ownership structure. However, risks due to the changing network structure of balance sheets are not priced in the financial assets in this model. We include that component in Model B through the risk channel. The incremental effects from Model A to Model B hence measure the effects of this change in insolvency risks due to the new network structure. However, the incremental effects may depend on the existing channels. To see this, observe that with the added risks, asset prices would drop, and this could trigger an entity to default, generating new losses to the system. If the existing channels of shock transmission do not allow the added losses to spill over to other players, the incremental effects may be small. On the other hand, if the existing channels provide paths to vulnerable players who are likely to spread losses further, this may in turn affect the network structure due to asset sales and liquidity withdrawal activities, causing the network to continue to change, and the risks to continue to rise.

We add the market channel in Model C which allows for the fire-sale effects. This of course creates new linkages among all players, and the interactions between the existing channels and the new ones can be complex. We do not try to explain every mechanism in this complex system, which might be impossible to do, but rather to investigate what is the added impact when an additional channel of shock transmission is allowed. We expect that when the market channel is included into the model, the asset prices of generally tradable assets such as bonds and equities may get more impact from the same type of shock. As a result, the values of mutual funds may change significantly too.

The panic selling effects are added in Model D. So in this model households play a more important role as asset sellers. Selling by households due to panic may amplify the effects of losses especially for the markets or sectors that are closely connected to households. The final model, Model E, includes the bank deleveraging effects. This model has all the amplification effects and shock transmission channels considered in this paper.

4.5.3 Industry shocks

In this section we perform stress testing by shocking each of the seven industries of the NFC sector (i.e. excluding NFCs in OTHER). We stress test one industry at a time. This shock is assumed to be an exogenous shock representing losses in the industry. This type of shock causes the industry to sell assets to raise liquidity to cover the losses. The losses can spread to other players through the channels of contagion and the amplification effects can magnify the damages. We set the shock size to 10-50 percent of the size of non-financial assets held by the industry. Note that the shock size at 50 percent is very large and may happen with extremely low probability. However, we choose to include such large shock sizes in this exercise to find the point where the system breaks down to help us better evaluate the stability of the system.

Figure 4.1 shows the plots of the effects on the size of the total assets of the entire NFC sector when a given industry is shocked. In each plot, the *x*-axis represents the shock size in percentage and the *y*-axis represents the percentage decrease in the total asset size of the entire NFC sector. The title of each plot represents the industry that experiences exogenous shocks. For example, the top-left plot shows the percentage decreases when the AGRO industry is hit by shocks of various sizes. We divide the decreases in the total assets into five regions in accordance with the five model specifications. The bottom layer (blue) represents the effects of shocks when only the liability and ownership channel is included (model A). The next layer (red) captures the incremental effects from the risk channel (model B). The third layer (yellow) is the incremental shock effects when the market channel is added (Model C). The fourth layer (purple) shows the incremental effects from panic selling (Model D). The top layer (green) captures the added effects due to bank deleveraging.

From Figure 4.1, we can see that the effects of shocks on the total assets of the NFC sector increase



Figure 4.1: Effects on total assets of the non-financial corporation (NFC) sector

This figure shows the percentage losses in the market value of the total assets of the entire NFC sector due to stress testing each of the NFC industries at various shock sizes. The shock size is represented as the percentage of the non-financial assets of the shock-initiated industry.

Note: Refer to the beginning of Section 4.1 for abbreviations. Source: Authors' calculations.

linearly in shock sizes for shock sizes of around 10-30 or 40 percent. But when the shocks get larger at 40 or 50 percent, the effects increase at much higher speeds for most shock-initiated industries. The results, not reported here, show that the jumps in the effects happen together with a jump in the number of bank defaults. For example, when the shock size of the AGRO industry is increased from 30 to 40 percent, the reduction in the total assets of the NFC sector jumps up from less than 4 percent to almost 40 percent in Model E, and the number of defaulted banks jumps from one bank to 32 banks, out

of 36 banks in the system. This shows that there is a threshold beyond which the system breaks down. In the AGRO case, the threshold is between 30-40 percent in terms of the shock size. When the shock size is increased to 50 percent, the effects seem to be stable implying that the loss transmission channels have been destroyed together with those defaulted 32 banks, which used to act as intermediaries in the financial system. Shocks from two industries, CONSUMP and TECH, seem to generate relatively small effects on the entire NFC sector. The number of defaulted banks for these two industry shocks is no more than two even at the shock size of 50 percent.

Now let us investigate which component of the model causes these decreases in the total assets of the NFC sector. For all industry shocks, the liability and ownership channel plays an important role in shock transmission, particularly for small shock sizes, where most of the effects come from this channel. When the shocks get larger, the effects from the market channel (fire sales) kick in and contribute more to the shock effects in most industry shocks. The importance of the fire-sale effects happens when a large number of banks default and have to liquidate their assets. The fire-sale effects do spread the losses and amplify the shock effects. Figure 4.1 shows that the AGRO industry is the only industry that has sizable effects from panic selling. Meanwhile, the bank deleveraging effects contribute somewhat for the shock initiated in the RESOURC industry, which might borrow from relatively highly leveraged banks, but the contribution seems to be small for other industry shocks. Effects through the risk channel are not noticeable for any of the industry shocks.

Next we look at the decreases in the total asset value of the entire banking sector. Figure 4.2 shows the plots of the percentage decreases in the total asset value of the banking sector for each industry shock at various shock sizes. The pattern of how shocks are transmitted to banks is similar to the pattern of how shocks are transmitted to NFCs, except that the magnitude is much larger for most industry shocks. In other words, as losses from one industry get larger, damages are spilled over to the banking sector more than the NFC sector. This could simply be because banks are intermediaries in the system.

Figure 4.3 shows the effects of industry shocks on the total fund value. Similar to the total assets of the NFC and banking sectors, the effects on the value of the mutual fund industry get larger at higher speeds as the shock size increases. However, the changes in the network structure, and hence insolvency risks, do have significant impacts on the value of the mutual fund industry (red region). Results not reported here show that the effects due to changing network structure do influence the value of the equity markets, and hence the values of mutual funds that hold stocks. However, such effects do not have a significant impact on bond values. Another interesting observation from Figure 4.3 is the noticeable size of the effects of panic selling for every industry shock. As a large portion of fund holders are households, panic selling by households does amplify the shock effects on the fund values. The fire-sale effects still contribute a lot to the decreases in the mutual fund value. Like the effects on the total assets of NFC and banking sectors shown in Figures 4.1 and 4.2, shocks initiated from the CONSUMP and TECH industries have smaller effects than those initiated from other NFC industries.

Effects on deposits and short-term loans are similar to those on the total value of banks as deposits and short-term loans are mostly related to the banking business. When the size of the banking industry reduces, the deposits and short-term loans shrink. The effects on bonds are similar to those on the total assets of the NFC sector, except that the liability channel contributes less as a big portion of the bond markets are issued by the government and the central bank, which do not default under our assumption.



Figure 4.2: Effects on total assets of the banking sector

This figure shows the percentage losses in the market value of the total assets of the entire banking sector due to stress testing each of the NFC industries at various shock sizes. The shock size is represented as the percentage of the non-financial assets of the shock-initiated industry.

Note: Refer to the beginning of Section 4.1 for abbreviations. Source: Authors' calculations.

In summary, shocks from one industry do spread to the banking sector and other NFC industries. The CONSUMP and TECH industries seem to be less connected to the system as shocks initiated from these two industries cause a lower degree of impact on the system. Comparing with the NFC sector, banks absorb the losses more as they are intermediaries. The losses are transmitted through the liability and ownership relationships. But when the losses are sufficiently large, the fire-sale effects become much more important, and they can amplify the overall effects of the shocks. Losses spread to all financial

Figure 4.3: Effects on fund values

This figure shows the percentage losses in the market value of the mutual funds in the system due to stress testing each of the NFC industries at various shock sizes. The shock size is represented as the percentage of the non-financial assets of the shock-initiated industry.



Note: Refer to the beginning of Section 4.1 for abbreviations. Source: Authors' calculations.

assets. Fire sales and higher insolvency risks reduce the asset prices. The effects of increased insolvency risks are crucial to the values of equities and funds, as these asset classes have the lowest seniority on asset claims and as a result are the most sensitive to insolvency risks.

4.5.4 Bank reputational shocks

In Thailand, large commercial banks tend to have associated or subsidiary asset management companies (AMCs). When there is a loss of confidence in the bank, it could spread to its associated or subsidiary AMC, and vice versa. In this section, we introduce a panic shock hitting each major bank and its associated mutual funds in the form of significant deposit withdrawal from the bank and investment fund share redemption from the mutual funds. This shock could represent a scenario where depositors and fund holders lose confidence in the bank and its associated mutual funds, which may be due to bank frauds or bad reputation of management teams. In the stress test, we vary the shock size, which is defined as the percentage of deposits and fund shares held by households. Once the shock hits this bank-AMC pair, that percentage of deposits and fund shares are withdrawn by households.

We study the effects from this type of shock based on the average effects across six major bank-AMC pairs. The results do not vary much among the six pairs, and the average results preserve the same properties found in each individual pair. We first look at the effects on the total assets of the entire NFC sector, and of the banking sector. Those effects are shown on the top row of Figure 4.4. Overall, the effects appear quite small compared to those of the industry shocks considered in the previous section. On average, the total asset value of the NFC sector reduces by less than 1 percent and that of the banking sector reduces by less than 4 percent at the 50 percent shock size. The liability and ownership channel is the important channel of shock transmission. As banks need liquidity from deposit withdrawal, they will stop renewing short-term loans to their borrowers, which account for a large portion of their assets. Consequently, borrowers, including NFCs, need to sell assets to pay back short-term loans as rollovers become more difficult. Hence, the liquidity withdrawal plays a major role in transmitting the shock, reducing the balance sheets of the NFC and banking sectors. In the second and the fourth rows of Figure 4.4, we present the effects on the sizes of deposits and short-term loans in the system, respectively. As we can see, the liability and ownership channel is the most important channel of shock transmission for these two types of financial assets, confirming our explanation above.

Figure 4.4 also shows the shock effects on the values of bond, equity, and fund markets. Effects on the fund values are driven mostly by the liability and ownership channel too, as the shock directly reduces the fund sizes due to fund redemption by major holders, namely households. On the other hand, the liability and ownership channel does not affect the sizes of the bond and equity markets. This is because these two markets are not subject to liquidity withdrawal risks, and when the effects are small and no default occurs, the liability and ownership channel does not function as the shock transmission channel for these two markets.

Most of the results can be expected as shocks of this type do not trigger defaults under the range of shock sizes we consider here. The risk channel effects (red region) are significant to the values of equity markets and the mutual fund industry, as they are the most sensitive to insolvency risks. Likewise, the fire-sale effects through the market channel (yellow region) are important for bonds and equities, which are directly subject to fire-sale risks. The fire-sale effects spill over to the size of the NFC sector through the ownership channel, as NFCs also hold bonds and equities.

The panic selling effects (purple region) have a significant impact on bond, equity, and fund markets as households sell those assets in panic selling. Such effects spill over to the size of the NFC sector as

This figure shows the percentage losses in the total assets of the entire NFC sector and the banking sector (top row), and in the market values of bonds, deposits, equities, mutual funds, and short-term loans in the system due to stress testing each of the major bank-AMC pairs at various shock sizes. The shock size is represented as the percentage of the sizes of deposits and fund shares held by households.



Source: Authors' calculations.

selling more bonds and equities further pushes the prices down through the market channel, and as the owners of these assets, the values of the assets of NFCs are lower. Some funds hold deposits with banks. With panic selling, more fund shares are sold and hence more deposits are withdrawn, reducing the deposit size. Banks as a result stop renewing short-term loans more. This explains the spillover effects of panic selling to the values of deposits and short-term loans.

Lastly, the bank deleveraging effects have a direct impact on the deposits, the short-term loans, and the size of the balance sheet of the banking sector. But when banks raise liquidity, they also sell their other assets such as bonds and equities, though at much lower amount. The fire-sale effects lower the prices, and the asset holders, including the NFC sector, lose in values.

Overall, although the effects from this type of shocks are relatively small compared to the effects from industry shocks, they cannot be overlooked. The largest impact happens to the value of the fund industry. The most important factor is panic selling. The reduction in the value of the mutual fund industry can be up to almost 20 percent on average for a shock size of 50 percent. In other words, a panic from households that triggers 50 percent deposit withdrawal and fund redemption of one of the major bank-AMC pairs could reduce the size of the whole mutual fund industry down by almost 20 percent on average.

5. Policy implications and further research areas

Throughout the past decade, the Thai financial landscape has evolved into an ecosystem that is more complex and interconnected, with a diverse group of financial service providers and a wide range of financial transactions. As of end-2017, the Thai financial system accounted for about 2.7 times of GDP.²² Commercial banks continued to have the largest share of 45.8 percent of total FIs' assets. Besides commercial banks, other FIs that played a key role included government's SFIs, mutual funds, insurance companies, as well as savings and credit union cooperatives. These institutions accounted for 15.4, 11.8, 9.1, and 6.5 percent of total FIs' assets, respectively.²³ These entities have been growing over the years and are now tightly integrated with Thailand's bank-centric financial system. Meanwhile, Thai capital markets have also been growing both in size and significance. As of end-2017, the total market capitalization of the Stock Exchange of Thailand (SET) and the Market for Alternative Investment (mai) stood at 17.9 THB trillion or 116.0 percent of GDP, or about 2.1 times of the size at end-2010. Fund raising via corporate debt issuance has also been growing gradually, as reflected in the total corporate bonds outstanding that stood at 3.3 THB trillion or 21.2 percent of GDP at end-2017, or about 2.7 times of the size at end-2010.²⁴

The increased complexity and interconnectedness in today's financial markets pose several challenges to regulators in their mission of safeguarding financial stability. Four key challenges are highlighted and discussed briefly below.

Scope of macroprudential oversight

With higher complexity and interconnectedness in today's financial system, macroprudential oversight needs to expand in scope in order to fulfill its ultimate objective of containing systemic risks and ensuring financial stability. Macroprudential policy must reach beyond the banking sector and encompass non-bank FIs and market-based financing activities in order to overcome the regulatory boundary problem. By leaving non-bank FIs and market-based financing out of the macroprudential perimeter, regulators not only leave the door wider open for the emigration of credit intermediation away from the banking sector, but also close an eye on the inherent liquidity and leverage risks of securities financing and asset management activities.

The stress-testing framework developed in this paper attempts to capture the interactions of nonbank FIs and market-based financing, especially AMCs and their mutual funds, with the financial system at large. Key challenges remain in expanding the scope of our network-based stress test to include other important non-bank FIs (e.g. savings cooperatives), capturing new market and liquidity risks, and tracing the chain effects across the financial system. These will help reveal vulnerabilities in the nonbank financial sector and assess the potential for negative spillover to the rest of the financial system, most prominently due to fire sales or collective selling by investment funds and other investors. Agentbased models, which allow for endogenous determination of asset prices, can also be used to account for such complex interactions. Going forward, combining transaction-level data with enhanced balance sheet data of non-bank entities could significantly improve the ability of our system-wide simulations to inform the monitoring of risks that could arise from non-bank FIs.

²² The calculation uses GDP at current prices obtained from NESDB.

²³ For mutual funds, the calculation considers all mutual funds including MMFs.

²⁴ The calculation uses total corporate bonds outstanding obtained from ThaiBMA.

With the recent growth of non-bank FIs and market-based financing, non-bank regulators also need to recalibrate their roles. To date, the roles of non-bank regulators around the world, especially for capital market supervisors, have been mainly on investor protection. However, the growing systemic importance of non-bank FIs and market-based financing calls for an enlargement of the mandate of capital market supervisors to also take into account aggregate financial stability. Involvement of central banks is also an important ingredient, given their expertise in assessing systemic risks.

Responsibility and inter-agency coordination

Thailand's current legal framework does not assign financial stability oversight to any specific agency explicitly. However, the BOT has been playing the leading role, and this is natural given the bankcentric nature of the Thai financial system. Practically speaking, this is also facilitated by BOT's comprehensive databases and analytical capabilities. For the Thai financial system at large, existing collaborative mechanisms and policy forums also allow key regulators to share information and collaborate closely, which would ensure that each regulator looks beyond its traditional perimeter and takes a system perspective. Despite the existing coordination mechanisms, a formal assignment of responsibility for financial stability oversight will help reduce policy uncertainty, foster inter-agency coordination, limit unwarranted policy "leakages", and prevent accountability issues that could arise as a result of unclear mandates. As the complexity of the financial system increases and more risks start to emerge from outside the banking system, effective coordination will become an even more crucial element of the overarching institutional arrangement.

There remain a number of challenges and open issues surrounding macroprudential framework. For instance, macroprudential policy has been targeted mostly at the banking sector, but open questions remain on the appropriate instrument sets and strategies for coping with risks emerging from non-bank FIs and market-based financing, most of which are not so strictly regulated as banks. While these non-bank entities could serve as a spare tire to complement bank-based financing, they also create new risks that might warrant a macroprudential response. Regulators thus need to remain flexible in their tools and adapt with the ever-changing risk landscape. Further studies on macroprudential policy framework, including ex-ante and ex-post appraisals of macroprudential tools, are also important.

Leakages

As the financial system becomes more diverse and complex, the issue of regulatory arbitrage or socalled "leakage" is essential. Stricter macroprudential requirements might increase incentives for banks to exploit their awarded flexibility under the regulatory framework in an unwarranted way. Banks might have incentives to circumvent regulation by moving certain activities into a less or differently regulated part of the financial sector. For example, banks might shift some activities off-balance sheet by moving them to entities that are not consolidated for prudential purposes (e.g. their subsidiary AMCs' mutual funds). This could make banks more prone to step-in risks, as they might be incentivized to guarantee losses of such entities in a crisis situation. On top of banks' actions discussed above, the expansion of non-bank FIs also facilitates the migration of activities toward the non-bank financial sector. Several trends observed in the recent years, such as the rapid growth in market-based financing and credit creation by non-bank FIs, could be read as an evidence of the so-called "waterbed effect", where regulations on banks have contributed to the growth of the non-bank financial sector. All these point toward the urgent need for an effective framework to monitor and address systemic risks arising from the non-bank financial sector.

Interactions with other policies

Aside from macroprudential policy, other policies also play a key role in containing risks in the financial system, and their interactions with macroprudential policy could lead to policy synergy or tension. For example, in achieving its primary objective of price stability, monetary policy might have undesirable side effects on financial stability in the short run. Expansionary fiscal policy might encourage over-indebtedness and make households more vulnerable to shocks. Some microprudential policy, while strengthening individual institutions, might increase the vulnerability of the financial system as a whole to systemic risks. A systematic coordination across policy spheres is thus vital for mitigating potential conflicts across policies and formulating optimal policy responses for the whole financial system.

The coordination between macroprudential and monetary policies is particularly important, because monetary policy tends to have a strong influence on credit growth, asset price dynamics, and risk-taking behaviors, all of which are at the heart of financial stability. However, the coordination cannot go too far because price stability, the main objective of monetary policy, is not within the remit of macroprudential framework. There has been a debate over the role that monetary policy might play in addressing financial sector imbalances and how monetary and macroprudential polices should be coordinated. These issues are important areas for further research.

6. Conclusion

This paper conducts in-depth profiling and stress-testing exercises that leverage on sectoral and disaggregated balance sheet data of players in the Thai financial system. For the first part of the study, empirical profiling has been conducted both at the sectoral and granular levels, and several aspects of the financial landscape have been documented. We find that interconnectedness in the financial system has risen and become more complex. The three main pillars of the financial system continue to be households, banks, and firms. Banks continue to dominate financial intermediation, with their two-way relationships with households via loans and deposits continuing to be the largest and the most important linkages in the financial system. But structural changes have been ongoing, with the landscape increasingly tilted toward OFCs. Mutual funds and insurance companies, in particular, have gained a steadily rising share of households' financial wealth, and their investment in securities issued by many sectors makes them an important source of funds. With regard to shock propagation, the balance sheet profiles of NFCs and OFCs suggest that they are the key players that could distribute shocks to many parts of the financial system. By having a diverse pool of creditors and issuing most liabilities in form of equities, adverse shocks to NFCs could be passed to many sectors at once. By investing in instruments issued by many sectors, adverse shocks to OFCs especially investment funds could lead to liquidity concerns to the issuing sectors. With regard to network topology, players in the financial system are linked via multiple instruments. There is a core cluster with dense connections where households, firms, D-SIBs and a few medium-sized banks, as well as some mutual funds of large banks' asset management arms are located, indicating that all these players are tightly connected. Topologically, banks are segmented into "core" commercial banks, government's SFIs, and foreignrelated entities, which reflect the different natures of their involvements with the rest of the financial system.
To test the resiliency of the financial system based on granular balance sheet interlinkages, a stresstesting framework based on a network model of financial contagion has been developed. In our model, shocks can be transmitted through the liability and ownership channel, the reverse liquidity channel, and the market channel (i.e. fire sales). Two shock amplification effects, namely panic selling and bank deleveraging, have been included to model behavioral responses during stressed times. We conduct stress testing based on two types of shocks: industry and bank reputational shocks. For the former, we introduce exogenous shocks representing losses to each NFC industry at varying intensity, and observe their impact on other players' assets (or net assets in case of mutual funds). We find that shocks to one industry do spread to banks and other industries, with banks suffering larger losses than industries. Losses generally propagate through the liability and ownership channel, as well as the reverse liquidity channel. But when the losses are large enough, the fire-sale effects become dominant, with panic selling reinforcing the negative effects mostly through equities and fund shares. For bank reputational shocks, we simulate a loss of confidence in major banks by introducing significant deposit withdrawal and fund redemption from banks and their subsidiary AMC's mutual funds. While the overall losses are much smaller than those resulting from industry shocks, these risks cannot be ignored since the mutual fund industry stands to suffer the most and panic selling could amplify the losses significantly.

Several policy implications could be drawn for financial stability oversight. First, as players in the financial system become more intricately interconnected, macroprudential policy must go beyond the banking sector and encompass market-based intermediaries, and this clearly requires inter-agency efforts. To succeed, formal assignments of responsibilities and clear mandates need to be laid out. Second, stricter regulations may push banks to move activities into a less or differently regulated segment of the financial sector, which might have already happened as reflected from OFCs' rapid growth in recent years. A framework to monitor and address non-banks needs to be developed. Third, a well-calibrated coordination across policies is needed to mitigate possible conflicts and achieve optimal results. This is especially the case for the interactions between macroprudential and monetary policies.

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