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DENMARK

FINANCIAL SECTOR ASSESSMENT PROGRAM

August 2020

TECHNICAL NOTE—FINANCIAL SECTOR INTERCONNECTEDNESS AND CONTAGION RISK ANALYSIS

This Technical Note on Financial Sector Interconnectedness and Contagion Risk Analysis for the Denmark FSAP was prepared by a staff team of the International Monetary Fund as background documentation for the periodic consultation with the member country. It is based on the information available at the time it was completed in July 2020.

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FINANCIAL SECTOR ASSESSMENT PROGRAM

July 15, 2020

TECHNICAL NOTE

FINANCIAL SECTOR INTERCONNECTEDNESS AND CONTAGION RISK ANALYSIS

Prepared By

Monetary and Capital Markets Department
DN Financial Stability Department
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This Technical Note was prepared by IMF staff in the context of the Financial Sector Assessment Program in Denmark. It contains technical analysis and detailed information underpinning the FSAP's findings and recommendations. Further information on the FSAP can be found at http://www.imf.org/external/np/fsap/fssa.aspx

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Glossary

AE	Advanced Economy
AFS	Available for Sale
CAR	Capital Adequacy Ratio
CCoB	Capital Conservation Buffer
CCyB	Countercyclical Buffer
CET1	Common Equity Tier 1
CoMap	Contagion Mapping Framework
COREP	Common Reporting Framework
CRD	Capital Requirements Directive (EU)
CRR	Capital Requirements Regulation (EU)
DFSA	Danish Financial Supervisory Authority
DN	Danmarks Nationalbank
EA	Euro Area
ELA	Emergency Liquidity Assistance
EM	Emerging Market
EU	European Union
FE	Financial Entities
FINREP	Financial Reporting Framework
FSSA	Financial System Stability Assessment
GDP	Gross Domestic Product
GFC	Global Financial Crisis
HH	Household
HQLA	High Quality Liquid Assets
IMF	International Monetary Fund
LCR	Liquidity Coverage Ratio
LGD	Loss-given-default
MCI	Mortgage Credit Institution
LE	Large Exposures
LTV	Loan-to-value Ratio
NFC	Non-financial Corporations
NOR	Nordic Region
PD	Probability of Default
ROW	Rest of the World
RWA	Risk Weighted Assets
SIFI	Systemically Important Financial Institution
STeM	Stress Test Matrix (for FSAP stress tests)
TN	Technical Note

EXECUTIVE SUMMARY

COVID-19 pandemic: The Financial Sector Assessment Program (FSAP) work was conducted prior to the COVID-19 pandemic, so this Technical Note (TN) does not assess the impact of the crisis or the recent crisis-related policy measures. Nonetheless, given the FSAP's focus on financial system structure and vulnerabilities, the findings and recommendations of the TN remain pertinent.

The FSAP developed a novel multi-layer contagion model to analyze financial system interconnectedness using a new and comprehensive database. This new infrastructure, based on securities data and newly-released confidential credit register data, plays a pivotal role in the development of an advanced contagion model that distinguishes the transmission of shocks between eight different exposure types or layers (loans, deposits, reverse repos, covered bonds, other debt securities, equities, unlisted shares, and other claims). The exercise focuses on the banking system (banks and MCIs), and on interconnections through the covered bond market, as the cornerstones of the overall financial system. However, it also includes exposures vis-a-vis non-bank financial institutions (insurer, pension and investment funds) and non-financial sectors (households, corporates), both domestically and abroad. The simulation exercise consists of a series of idiosyncratic shocks, where the default of each node is triggered iteratively. The model introduces a repricing channel on traded securities to capture cascade effects arising from market reactions to changes in an entity's solvency condition.

MCIs play a central role in the domestic interbank system. Focusing initially on the domestic banking system illustrates that MCIs take center stage in the network, interconnecting systemic and non-systemic banks through covered bond exposures. The full network highlights the strong connections between the Danish banking system, the domestic corporate (in particular, CRE) and household sectors (via loans), and domestic institutional investors (via securities). Cross-border exposures are especially strong vis-a-vis the Nordic region and the euro area financial system.

The analysis reveals that Danish banks and MCIs are mostly exposed to shocks originated within the banking system.

- MCIs are a key source of outward spillovers and induce the highest levels of contagion losses through unlisted shares (reflecting complex group structures) and covered bond exposures.[1] Contagion is transmitted predominantly through credit losses; cascade effects owing to the repricing channel (which captures market reactions to weakening capitalization of MCIs and banks) affects materially only one non-systemic bank.
- Systemic banks, on average, are more vulnerable to inward spillover losses owing to their covered bond holdings. More generally, the domestic banking system is susceptible to cross-border financial spillovers from the Nordic region and the euro area (including via interbank loans and deposits). The cascade effects from losses in subsequent rounds within the banking system remain limited. Taken together, given their high contagion and vulnerability scores, the analysis identifies four credit institutions with the ability to amplify spillovers across the financial system.

[1] The analysis considers financial institutions individually (and not as groups).

Table 1. Denmark: Key Recommendations	
Recommendations and Authority Responsible for Implementation	**Time[1/]**
Interconnectedness and Contagion Risk Analysis	
Close data gaps, including the coverage and quality of bilateral exposures (asset and liability positions) of financial entities, and enhance the data infrastructure to link securities data and credit register with balance sheet of financial entities, (DN).	ST
Develop a system-wide contagion risk model and incorporate these contagion effects into the overall macroprudential stress testing framework, which can then also be used for regular systemic risk monitoring (DN).	ST
[1/] ST: Short term (1-3 years); MT: Medium Term (3-5 years).	

INTRODUCTION[2]

1. **Denmark's large financial system (at 630 percent of GDP) reflects in part the high level of interconnectedness between financial institutions, households and corporates.** The Danish covered bond market is a mainstay of the Danish mortgage system with more than 200 years of history. Covered bonds are held widely by banks and institutional investors, both domestically and abroad; they are primarily issued by mortgage credit institutions (MCIs), which provide mortgage finance to the household sector.[3] Household wealth, comprising mainly housing and pension assets, is among the highest in the world, but so is household debt.[4] Thus, MCIs take center stage in a highly interconnected financial system, while household debt and real estate prices are considered key vulnerabilities for systemic risk analysis.

2. **Given the high degree of financial interconnectedness through the covered bond market, understanding the resilience of this market, and more broadly contagion risks and shock transmission channels, are crucial for safeguarding financial stability.** As highlighted in 2014 FSAP Technical Note (IMF, 2014), the importance of these interdependencies is accentuated by the small number of covered bond issuers, which means that risks materializing in one institution could quickly spread across the entire system. The large size of the covered bond market as a percentage of Danish GDP suggests that this interconnectedness is relevant for the overall economy.

3. **Against this backdrop, a team of IMF and DN staff developed a new analytical framework for interconnectedness and contagion risk analysis.** The teams worked collaboratively to develop a data infrastructure and a new multi-layer network model where contagion risks are examined from cross-sectoral and cross-border perspectives. The assessment of contagion risks is conducted mainly using model-based simulations applied to a novel dataset that reconciles two confidential and complementary micro-data sources: securities data and the newly released credit register. This network analysis builds on the CoMap (Covi, Gorpe, and Kok 2019) framework to develop a multi-layer model with eight different instrument types. This novel feature further enables the introduction of a market repricing channel, which is particularly important to model how risks related to covered bonds might be transmitted in the financial system.

4. **The remainder of this technical note (TN) is structured as follows.** The second chapter presents an overview of the interconnectedness of the financial system and highlights potential

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[2] This note was prepared by Mario Catalán and Mehmet Ziya Gorpe (both IMF), and Birgitte Vølund Buchholst, Amalie Christensen, Karen Holm Laursen, and Giorgio Mirone (all DN). The FSAP team would like to express its deepest gratitude to the authorities for their close cooperation and support in facilitating this comprehensive exercise.

[3] MCIs business activities are limited to the provision of mortgage loans (legally they are not allowed to accept deposits). The loans must be funded by the issuance of covered bonds backed by assets segregated in bankruptcy remote capital centers (which are still on the balance sheet of the MCI), and a residual claim (ranking senior to non-covered bond creditors) on the general balance sheet if the assets of the capital center cannot fully cover the investor's exposure. A margin over the covered bond cost is charged to cover administrative costs, risk, and profit.

[4] Institutional investors in this TN loosely refer to pension funds, insurance companies and investment funds.

areas where contagion risks could materialize from concentration of exposures. The third chapter features a novel multi-layer contagion mapping (CoMap) model to analyze contagion risks and presents the results as well as the sensitivity analysis. The final chapter concludes with a summary of the exercise and discusses the path forward.

INTERCONNECTEDNESS IN DENMARK

A. Overview of Interlinkages

5. This overview looks at not only the interconnectedness within the Danish financial system but its cross-sectoral and cross-border interlinkages to present a more comprehensive picture of the system. Having a system-wide perspective can shed light on where contagion risks might be most concentrated and how they might be transmitted through the network of entities. Figure 1 shows these cross-sectoral and cross-border interlinkages as of December 2018, based on publicly available aggregated data.[5]

- *Credit institutions (both banks and MCIs)* are at the core of the system and seem to be highly interconnected to each other through loans and guarantees, fixed income (including covered bond) exposures, and ownership links within financial group structures.

- *Pension funds and insurance companies* have significant exposures to credit institutions and could amplify stress mainly through liquidation of their large covered bond exposures—fire sales impacting the covered bond market.

- *Households* hold pension and housing wealth constituting around 70 percent of their wealth (see Figure 3). Any substantial housing price shock that reverberates through MCIs and is passed onto the pension and life insurance sectors will likely exacerbate the wealth effect and might result in further downside risks.

- *Cross-border linkages* via exposures to counterparties in the rest of the world (ROW) are significant for all sectors and similarly depending on the counterparty/country concentration could be detrimental;

- *Intra-linkages* in the non-financial corporate (NFC) sector is worth noting in that exposures among NFCs (through 75 percent equity/shares and 25 percent intercompany lending) are highest of any intersectoral linkages in the system.

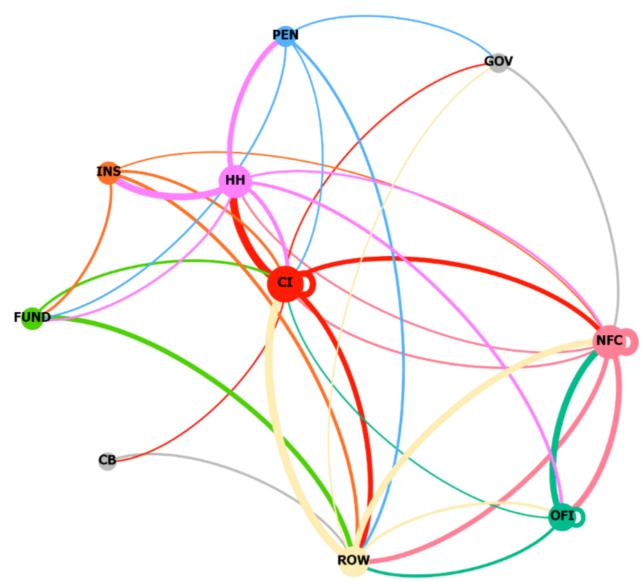
6. Mortgage-based covered bonds play a prominent role in the Danish financial system and are likely contributing to increased interconnectedness. While the financial accounts data doesn't distinguish covered bonds separately, the general knowledge about the size and prominence of covered bond holdings is consistent with the strong linkages both within the banking

[5] Financial Accounts Data, DN.

system and its interlinkages with institutional investors through debt securities. These observations support the analytical approach to incorporate not only all relevant financial institutions (credit institutions, insurers, pension funds, and investment funds) but also households and corporates as potential sources or conduits of contagion. This broad approach is necessary because the covered bond market acts as a cornerstone that integrates the various types of institutions which are large in Denmark, and the household sector holds sizable assets and liabilities vis-à-vis these institutions.

Figure 1. Denmark: Financial Flows within Denmark and with the Rest of the World (December 2018)

Network Map of Cross-sectoral and Cross-border Interlinkages



Heatmap of Interlinkages (billions DKK)

CREDITOR \ BORROWER	NFC	CB	CI	FUND	OFI	INS	PEN	GOV	HH	ROW	TOTAL
NFC	2,547	16	445	152	1,698	102	6	46	367	1,360	6,739
CB	-	-	38	-	-	-	-	-	-	474	512
CI	1,264	219	1,920	138	167	104	38	228	2,443	1,423	7,944
FUND	62	-	588	191	11	1	-	58	-	1,361	2,272
OFI	1,916	-	229	173	1,286	61	-	8	43	708	4,424
INS	205	-	625	575	67	54	-	87	4	840	2,457
PEN	145	-	261	311	84	1	10	277	1	575	1,665
GOV	463	196	118	29	7	3	5	180	128	11	1,140
HH	450	46	1,019	465	778	2,076	1,487	125	-	133	6,579
ROW	1,925	45	2,470	137	591	82	85	233	1	-	5,569
TOTAL	8,977	522	7,713	2,171	4,689	2,484	1,631	1,242	2,987	6,885	39,301

Sources: Danmarks Nationalbank. IMF staff calculations.

Notes: The sectors are labeled as follows: non-financial corporations (NFC), central bank (CB), credit institutions (CI), investment funds (FUND), other financial institutions (OFI), insurers (INS), pension funds (PEN), government (GOV), households (HH), rest of the world (ROW). Node size reflects the magnitude of total assets for each sector. Line thickness is proportional to the normalized size of bilateral links with respect to total system assets. Line color represents exposure direction, where it matches the color of the exposed sector for a given link.

B. Mapping of the Interlinkages in the Financial System

Credit Institutions (banks and MCIs)

7. There is a significant amount of exposures between the credit institutions (24 percent of overall exposures) in part due to cross holdings of each other's covered bonds (Figure 2). The small number of issuers in the covered bond market makes such interdependencies even more critical as it increases the likelihood of problems in one MCI having a widespread impact on others. The fact that covered bonds typically have very high ratings, receive exemption from large exposure limits and qualify as HQLA makes these securities a highly attractive and widespread form of investment, strengthening interconnectedness and potential transmission of risks between the banks and MCIs. Loans extended to households and corporates are credit institutions' largest exposures, together making up almost half their overall exposures. In terms of liabilities, the rest of the world with 32 percent is a key source, which likely includes significant foreign investment in MCIs' covered bonds. This is followed by household deposits, which account for 13 percent of the funding sources of credit institutions.

Institutional Investors

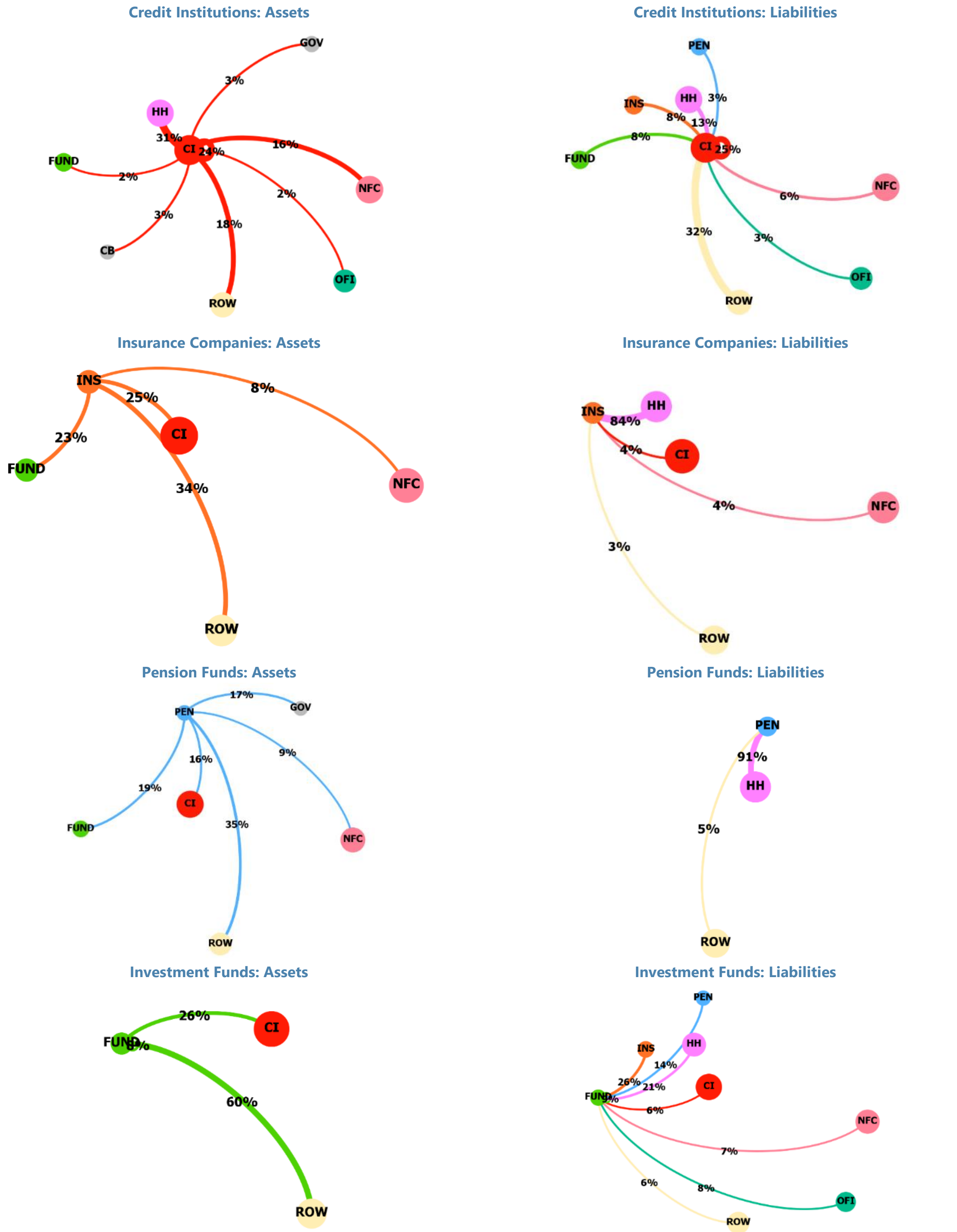
8. The large share of covered bonds held by domestic institutional investors contributes to high interconnectedness in the Danish financial sector.

- *The insurance sector,* largely comprising life-insurers, holds a significant share of assets with banks and MCIs (25 percent, see Figure 2).[6] Debt securities, likely to be mostly in the form of covered bonds, make up the bulk of these exposures (88 percent). Insurers place another 23 percent of their assets with investment funds. Their foreign assets portfolio makes up about one-third of their balance sheet and is dominated by equity investments. On the liabilities side, households are the prime market for the insurance sector, but they also have short-term liabilities vis-a-vis banks.

- *Pension funds,* while having a similar exposure to the rest of the world, have a more diversified domestic portfolio with a significant exposure to government securities (17 percent, see Figure 2). Their exposure to credit institutions are predominantly in debt securities and deposits with 72 and 16 percent shares, respectively. They also place about one-fifth of their portfolio with investment funds. On the liabilities side, apart from technical provisions due to households, pension funds have short-term debt liabilities vis-à-vis both domestic and foreign banks.

[6] While some dedicated pension funds exist in Denmark, life insurance companies dominate the market for mandatory pension schemes for employees, where major products are traditional life annuities with guaranteed interest rates as well as market-return products. Overall, average rate products, characterized by the pension savings accruing interest at a certain guaranteed average rate, still account for largest share of provisions, whereas, new pensions schemes are primarily market rate products. For more details, see Technical Note on Insurance Regulation and Supervision.

Figure 2. Denmark: Shares of Assets and Liabilities by Sector



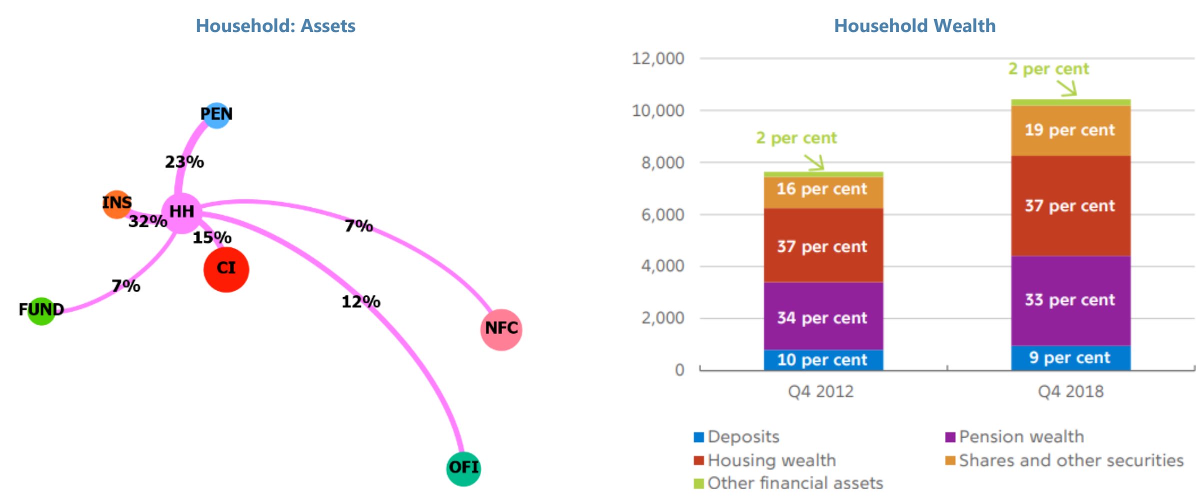
Sources: Danmarks Nationalbank, IMF staff calculations.

- *Investment funds* have a portfolio that is almost equally split between fixed income and equity securities (see Figure 2). Half of the fixed income portfolio comprises debt securities of domestic credit institutions, corresponding to around one quarter of their assets, while the other half is invested abroad. Of the equity portfolio, 75 percent is invested abroad while the rest is mostly held as shares in other funds.

Households

9. Housing and pension wealth make up the vast majority of household wealth (Figure 3). Households also hold an important share (15 percent) of their financial assets as deposits at banks, which is the largest deposit base for banks. At the same time, Danish household indebtedness is among the highest in advanced economies and, given their sizeable indebtedness, the financing conditions offered by MCIs and banks are of critical importance to households. Significant adverse shocks that impact the risk premium of covered bonds or undermine solvency or liquidity conditions for MCIs could translate into higher refinancing costs for households. Pension and life-insurance entitlements constitute a significant portion, a 33 percent share, of growing household wealth in Denmark with an additional 5 percent in investment fund shares. This means that the wealth effects due to a weakening balance sheet position of institutional investors could further exacerbate distress in the household sector. Particularly in a housing market downturn scenario, households could be hit by a double whammy, a direct shock to their housing wealth (37 percent share of total household wealth) and indirectly through asset prices impacting their pension wealth. Therefore, a confluence of factors – adverse interest rate, asset price, and income shocks – could reinforce macrofinancial feedback loops in a highly interconnected economy making household consumption more vulnerable.

Figure 3. Denmark: Household Sector



Sources: Danmarks Nationalbank, DN Financial Stability Report, IMF staff calculations.

CONTAGION RISK ANALYSIS

A. Coverage and Exposure Data

10. The exercise distinguishes between active and passive nodes in the network. This is mainly due to the nature and limitations of the micro data sources. While these data allowed access to highly granular information, its usability revolves around the universe of entities required to report such data on a regular basis, namely credit institutions. Accordingly, while the focus of the exercise is on how risks can be amplified through the active players in the banking system, it is able to incorporate a much larger universe of counterparts as passive nodes.

Coverage

11. The network analysis achieved a significant coverage of the Danish banking system, hereafter referred to as the *core network*. This *core network* consists of the 21 largest Danish credit institutions comprising 5 SIFI banks, 9 non-SIFIs (Tier 2 banks) and 7 MCIs.[7] They collectively account for 86 percent of the total assets of the Danish banking sector.

12. The *full network* is constructed by extending the coverage to non-bank financial entities and incorporating all other sectors and countries Danish banks have exposures to. This increases the network size to 1,005 nodes combining individual entities and sector-level aggregates as shown in Table 2.

Table 2. Denmark: Network Composition by Type and Location

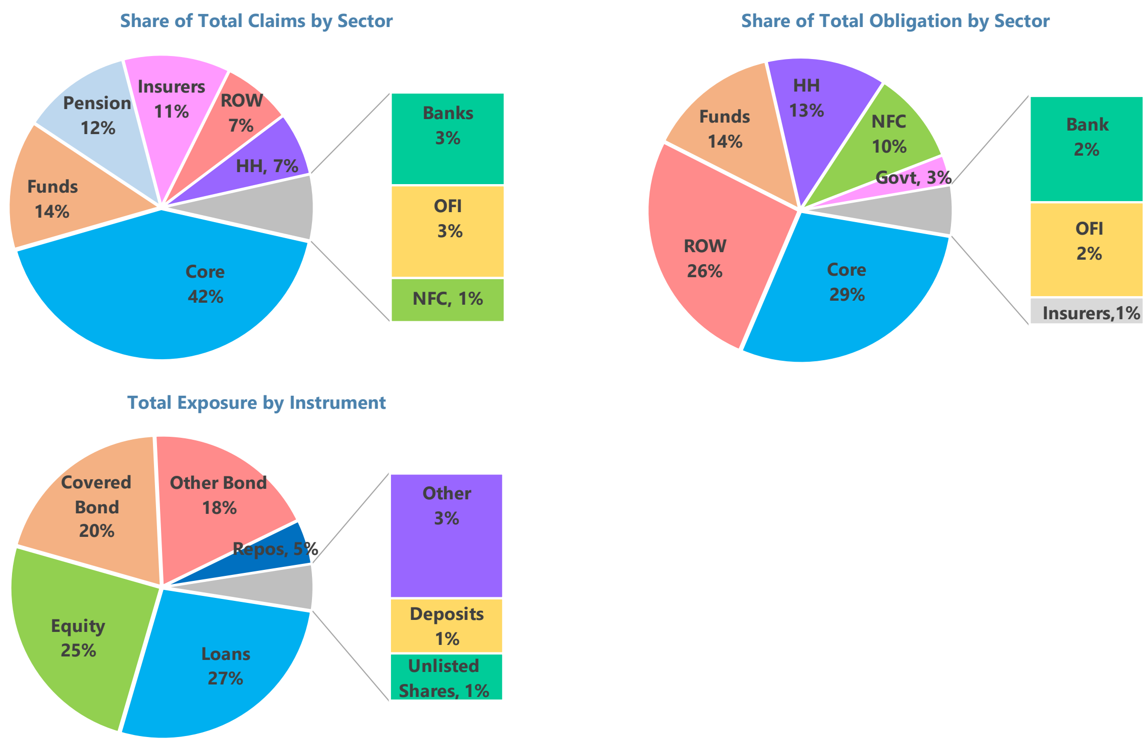
Network	Type of entity/sector	Denmark	Rest of the World (ROW)
	SIFI banks	5 entities	…
Core	*Non-SIFI banks*	9 entities	…
	Mortgage credit institutions	7 entities	…
	Credit institutions	109 entities	106 by country
	Pension funds	41 entities	5 by country
	Insurance companies	107 entities	40 by country
	Investment funds	Sector aggregate	43 by country
Non-Core	*Other financial entities*	Sector aggregate	99 by country
	Households	Sector aggregate	170 by country
	NFCs	21 industry aggregates	113 by country
	Government	1 entity	123 by country
	RoW	…	1
Full	*All*	**305**	**700**

[7] The groupings SIFI bank and non-SIFI bank follow DFSA's classification published on its website. In this note, MCIs are uniformly classified as MCIs whether they are SIFIs or not.

13. The core network has the largest share of exposures within the network at 42 per cent, and 29 percent of the total obligations, Figure 4 showing that these entities are at the core of the Danish financial system. Rest of the world has significantly less exposures (7 percent) to Danish financial system than their liabilities towards Danish entities (26 percent).

14. Data collected by the DFSA on the core network entities are derived from the common reporting (COREP), financial reporting (FINREP) framework and the DFSA's own reporting templates. It includes information on: capital ratios, capital requirements, total assets, risk weighted assets, unencumbered assets, high quality liquid assets and net liquidity outflow, etc. For other financial entities (insurance corporations, pension funds and investment funds) information on total assets is retrieved from statistics collected by DNB on these entities.

Figure 4. Denmark: Asset and Liability Exposures by Sector and Instrument



Sources: Credit Register, Securities Database, IMF staff calculations.

Exposure Data

15. The novel data on exposures encompasses micro-data from two primary sources: securities statistics and the new credit register. Both databases are enriched with data from other sources, e.g. counterparty information from the business register, etc. The exposures are categorized to 8 different types of instruments (Table 3):

- The first four types of instruments are loan level data sourced from the credit register. The classifications of these instrument types are based on the reporting requirements in the Regulation (EU) 2016/867 on the collection of granular credit and credit risk data (ECB/2016/13) supplemented by two Danish types of instruments to encompass Danish bond based loans, cf. the reporting guidelines to the Danish credit register. Sector and country information is available on the asset and liability side for these instrument types.

- The last four types of instruments are data on securities collected on a security by security level, which are classified in accordance with "The Handbook on Securities Statistics" published by the International Monetary Fund, Bank for International Settlements and European Central Bank. Information on investor sector and country is not available for holdings of Danish securities by foreign entities they are grouped in one single entity "RoW" (Table 2).

- Loans have the largest share in the breakdown of exposures by type of instrument covering 27 percent of the total exposures followed closely followed by equity with a quarter share of all exposures. Direct exposures to covered bonds account for 20 percent. This ratio would be significantly higher if indirect exposures, those underlying loans (59 percent) and repos, are also considered. The data doesn't include deposits from non-reporting credit institutions and loans provided to Danish counterparties from non-reporting credit institutions.

Table 3. Denmark: Type of Instruments in the Network

Instrument type	Source	Valuation	Comment
Loans	*Credit register*	Carrying amount	
Deposits (interbank)	*Credit register*	Carrying amount	Available if depositor is a reporting credit institution
Reverse repos	*Credit register*	Carrying amount	Including information on underlying security. Reverse repos are included when one of the involved counterparties is a reporting credit institution
Other loans	*Credit register*	Carrying amount	
Covered bonds	*Securities stat*	Market value	
Other debt securities	*Securities stat*	Market value	
Equity	*Securities stat*	Market value	
Unlisted equity/shares	*Several sources*	Book value	

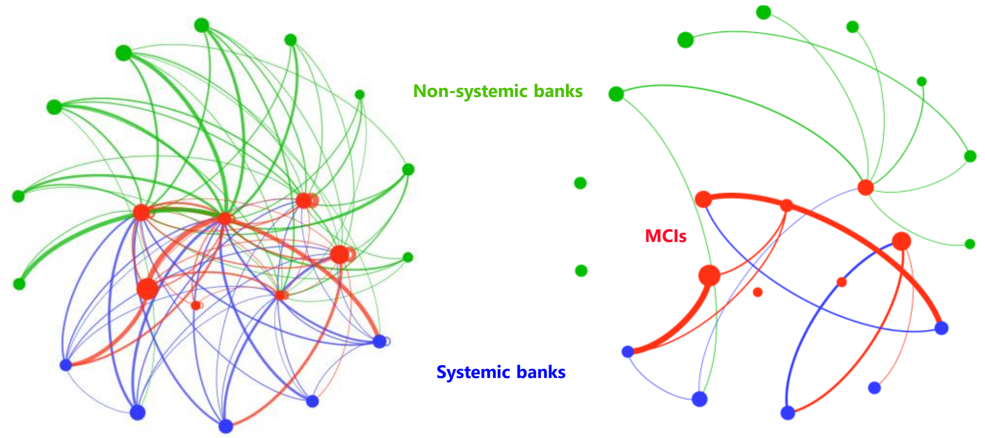
Network Topology

16. The graphical illustration of the financial interlinkages is twofold. Initially, the topology of the interbank exposures in the core network—key players of the banking sector—is plotted (Figure 5, upper panel). Red nodes representing MCIs are positioned in the center connected to each other and to the rest of the system with blue and green nodes representing systemic and non-systemic banks, respectively. The thicker the connections, the more significant they are to the exposed entity with the same color. The second plot depicts the full network of interlinkages with two concentric circles: an inner-circle comprising the same initial core network and an outer-circle including the most important counterparts with which the core entities have material exposures. This provides a more complete picture of the interconnections with other financial and non-financial sectors both in Denmark and outside.

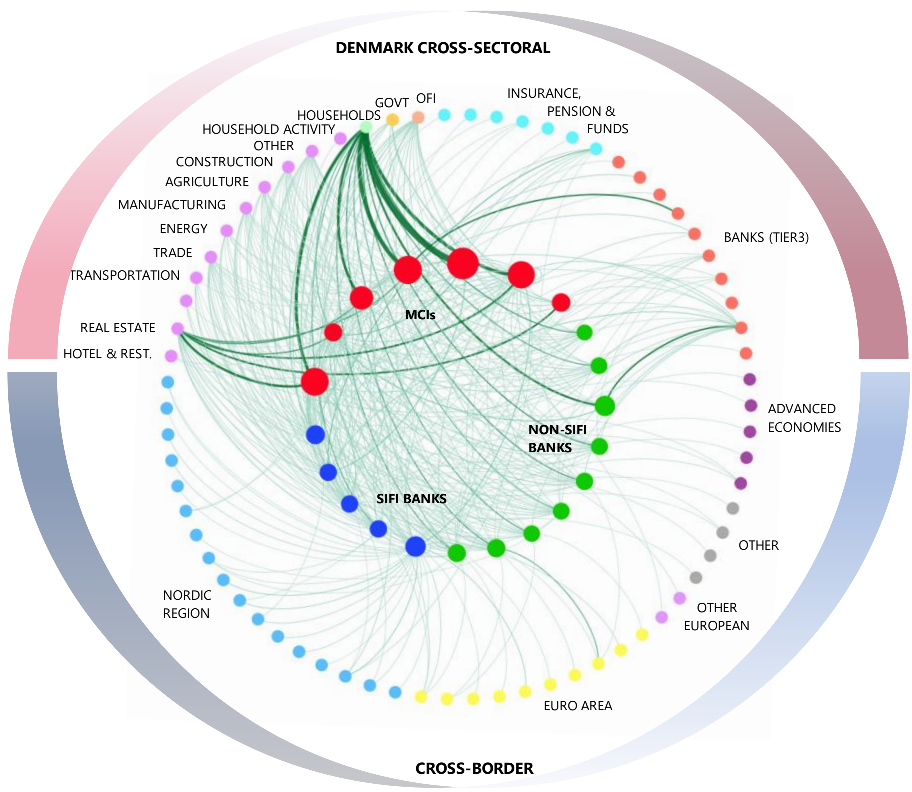
17. MCIs play a central role in the domestic interbank system. Focusing initially on the domestic banking system illustrates that MCIs take center stage in the network linking systemic and non-systemic banks through a dense network of covered bond exposures (Figure 5). The full network highlights the strong connections between the Danish banking system and the domestic corporate (in particular, CRE) and household sectors (via loans) and domestic institutional investors, which include insurers and pension and investment funds, (via securities). Cross-border exposures are especially strong with the Nordic region and the euro area financial system.

Figure 5. Denmark: Network Topology of the Financial System's Interlinkages (September 2019)

Core Network: Total Exposures | **Core Network: Excluding Cover Bonds**



Full Network of Significant Interlinkages Across Sectors and Borders



Sources: Credit Register, Securities Database, IMF staff calculations.

Note: The network graphs in the top panel comprises 21 credit institutions, classified as systemic banks and non-systemic banks as well as mortgage credit institutions (MCIs). The bottom panel includes other individual financial institutions in Denmark and sector-level aggregates of non-financial sectors in Denmark and sector-level aggreagates for cross-border exposures. Line thickness is proportional to exposure-to-capital ratio, and in the top panel matches the color of the exposed entity. Node size is proportional to number of exposures weighted by exposure-to-capital ratio. Thicker lines indicate higher degree of concentration vis-à-vis a counterparty normalized by exposed entity's capital and larger nodes indicate higher degree of vulnerability as measured jointly by the total number of exposures for each node and strength of those connections. Exposures that are less than 10 and 5 percent of exposed entity's capital are excluded in top panel and bottom panel, respectively.

B. Multi-layer Contagion Mapping Model (CoMap)

18. The CoMap framework (Covi, Gorpe and Kok, 2019) served as the starting point for the development of the multi-layer contagion model used in this exercise.[8] While the credit and funding transmission channels from the CoMap framework were maintained, a number of new and important extensions were introduced. Amongst these, a market repricing loop to capture market reactions to changes in entities' capitalization ratios is a noteworthy feature—and an important factor for covered bonds, which constitute the most significant relations between banks and MCIs. The following subsections describe each transmission channel and how they were modeled. Further details on the choice of modeling approaches are provided in Appendix I.

Credit Channel

19. Credit channel simulates an entity defaulting on its obligations to its counterparts and captures all transactions between such parties. Consequently, when an entity defaults, others in the network with direct exposures face potential losses. In response to a subset ($\mathcal{Y}$) of banks defaulting on their obligations, bank i's losses are summed across all banks $j \in \mathcal{Y}$ and claim types k using exposure-specific loss-given default rates, λ_{ij}^{k}, corresponding to its claim of type k on bank j, x_{ij}^{k}, multiplied by default ratio, η_{ij}^{k}, representing the share of the exposure being defaulted upon:

$$LOSS_i^{Credit} = \sum_{j \in Y} \sum_k \eta_{ij}^k \lambda_{ij}^k x_{ij}^k$$

Funding Channel

20. When an entity defaults, others in the network with direct exposures face potential losses. In response to a subset of banks defaulting, $\mathcal{Y}$, and thereby withdrawing funding from other entities in the network, bank i faces funding shortfall summed across all defaulting banks $j \in \mathcal{Y}$ using a funding shortfall rate, ρ_{ji}^{k}, specific to each exposure:

$$TFS_i = \sum_{j \in Y} \sum_k \rho_{ji}^k x_{ji}^k$$

21. Bank i can pledge any surplus HQLA (in excess of net liquidity outflows–NLO), γ_i, to central bank for immediate liquidity needs to offset TFS with the remaining liquidity shortage computed as:

$$max\left\{0, \sum_{j \in Y} \sum_k \rho_{ji}^k x_{ji}^k - \gamma_i\right\}$$

22. Bank i is pushed to deleverage by selling its unencumbered marketable assets at a discount (fire sale) if the remaining liquidity shortage is strictly positive. Considering that bank i has a limited pool of such assets, θ_i, with a discount rate, δ_i, calibrated based on the composition of those assets, its potential losses from fire sale is equivalent to:

[8] See Bricco and Xu (2019) for review and use of interconnectedness and contagion models used in FSAPs.

$$LOSS_i^{Funding} = \delta_i min\left\{\frac{1}{1-\delta_i}\ max\left\{0, \sum\nolimits_{j\in Y}\sum\nolimits_k \rho_{ji}^k x_{ji}^k - \gamma_i\right\},\ \theta_i\right\}$$

Market Repricing Channel

23. Once the shock is transmitted through the credit and funding channels to others, the affected counterparties realize losses, which are absorbed by their capitals. The signals about the capital of the affected banks could change the valuation of its debt securities due to credit spread. In this model, this market price impact is determined endogenously through a series of steps (see Figure 6 for a schematic view). It is important to note that while this channel applies to all debt securities, covered bonds are treated slightly differently as they can be partially insulated from the issuer's credit rating up to a certain extent (i.e., uplift buffer) as explained below.

- In the first step, the capital ratio is mapped to a rating category as a function of a bank's capital, $c_{j,t}$, and the general macro profile of the country, M_t, at time t. The initial level of capital and the change due to losses determines whether the bank gets downgraded and, if so, by how many notches.

$$R_{j,t} = g\left(c_{j,t}, M_t\right)$$

- This rating downgrade then puts upward pressure on the yield spread of the debt securities they issued. The change in the yield spread, Δy_j^k, is determined based on a migration matrix (from which rating, $R_{j,t-1}$, to which rating category, $R_{j,t}$). This yield spread change would reflect purely credit spreads due to an increase in such entity's probability of default. The uplift buffer is taken into account for the covered bonds as this would provide an additional room for covered bonds before a downgrade takes place.

$$\Delta y_j^k = f\left(R_{j,t}, R_{j,t-1}, k\right)$$

- The price impact, ΔP_{ij}^k, is then calculated by multiplying the yield change, Δy_j^k, with the modified duration, μ_{ij}^k, that corresponds to each exposure. This price impact results in valuation losses to those entities holding the securities of counterparties initially affected through the credit and funding channels.

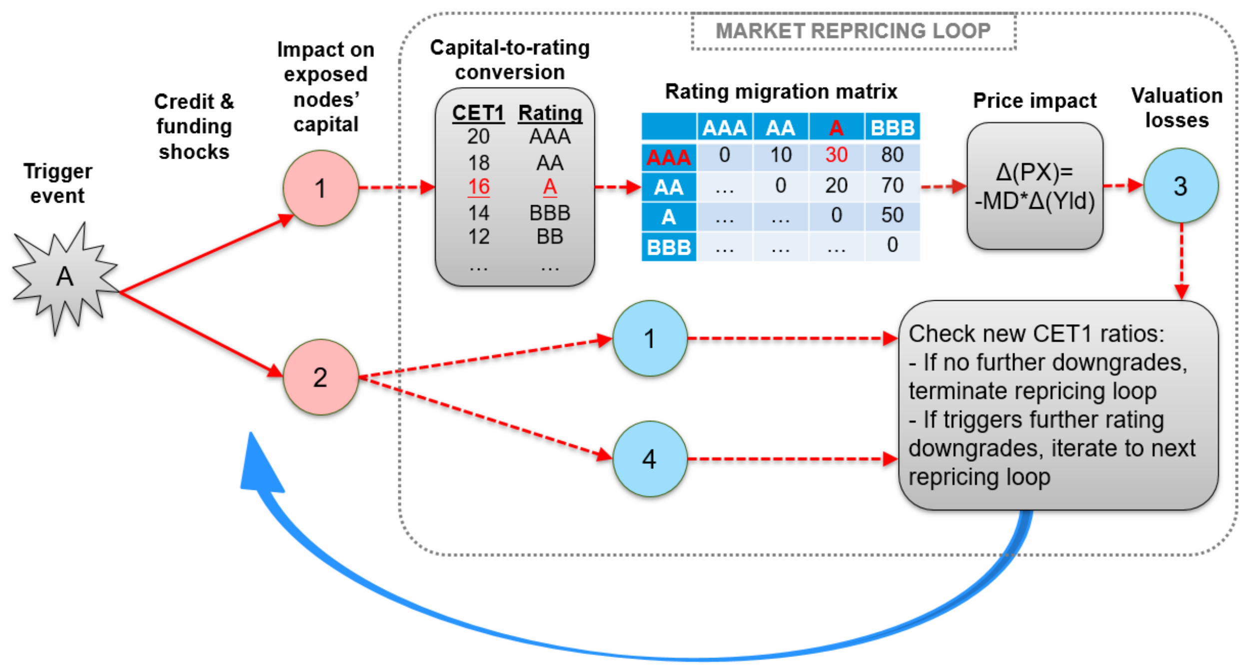
$$\Delta P_{ij}^k = \mu_{ij}^k \Delta y_j^k$$

- Consequently, these entities have to absorb losses, which can lead to rating downgrades. This would restart the market repricing loop again and this would continue until there is no further price impact that results in rating downgrades.

24. In summary, the market price impact takes into account: (i) the issuer, reflecting its capital ratio; (ii) the type of security, treating covered bonds differently from other debt securities; (iii) the maturity of the particular issuance(s) held by the exposed party, as captured by the modified duration.

$$LOSS_i^{Repricing} = \sum\nolimits_{j\in Y}\sum\nolimits_k P_{ij}^k x_{ij}^k$$

Figure 6. Market Repricing Channel: A Schematic View



Note: This illustration shows the sequence of events following the failure of node A, focusing on the mechanism of market repricing channel.

Other Features of the Model

25. Reverse repos and the underlying securities are fully accounted for in this model. Accordingly, each reverse repo exposure is mapped to the types and issuers of underlying securities along with the respective information on maturity, modified duration and loss-given default characteristics. The loss-given-default parameters are updated based on changes in the valuation of underlying securities in the repricing loop. When a reverse repo counterparty defaults, the lender takes full ownership of the underlying securities at the latest market prices. Lender might incur losses to the extent that the underlying securities have been previously repriced. Furthermore, the specific securities are transferred to the lender's balance sheet at the same time the original reverse repo exposure is settled.

26. The model also incorporates the group structure of individual entities by allowing for intra-group recapitalization in the exercise. When an individual entity incurs losses that would reduce its capital below the default threshold, it gets capital injection from an "able" parent entity sufficient to bring its capital to a level above a certain buffer. At the same time, the parent bank's capital is reduced by the same amount. If the parent entity does not have sufficient capital to recapitalize its daughter, the daughter entity defaults.

Default Conditions

27. Insolvency default: once the credit, funding and market repricing channels play out and intra-group capitalization option, if called, gets exercised, a bank's remaining surplus capital is compared to its total losses. The bank is considered to be in default due to insolvency if:

$$c_{i,t} - c_{i,min} < LOSS_i^{Credit} + LOSS_i^{Funding} + LOSS_i^{Repricing}$$

28. Illiquidity default: significant funding shortfalls may exceed banks' liquidity buffers and further may not be met by deleveraging via costly fire-sales. Therefore, if a bank has used up all its HQLA buffer and pool of unencumbered marketable securities, it is considered to be illiquid.

$$\theta_i < \frac{1}{1-\delta_i} max\left\{0, \sum_{j \in \mathcal{Y}} \rho_i x_{ji} - \gamma_i\right\}$$

Algorithm

29. The model is solved using a sequential default algorithm following the sequence of events as in CoMap, with some modifications to accommodate the multi-layer nature of the analysis and the newly introduced market repricing channel. The algorithm is implemented in the following way (see also Figure 7):

- At the outset, the idiosyncratic shock (default of an entity) is triggered, which sets in motion a series of transmission mechanisms in the following sequence:

    i. Reverse repos associated with the defaulted entity (or entities) are settled and underlying securities are transferred to the lender;

    ii. The entity defaults on its obligations resulting in losses to counterparts based on most up-to-date LGDs;

    iii. The entity withdraws funding that leads to funding shortfalls in affected counterparts;

    iv. Counterparts deleverage if they cannot meet funding shortfall using liquidity buffers;

    v. Market repricing loop kicks in if preceding losses lead to rating downgrades in the networks and iterates until there are no further downgrades;

    vi. Potentially insolvent banks receive recapitalization, if available, from solvent parents;

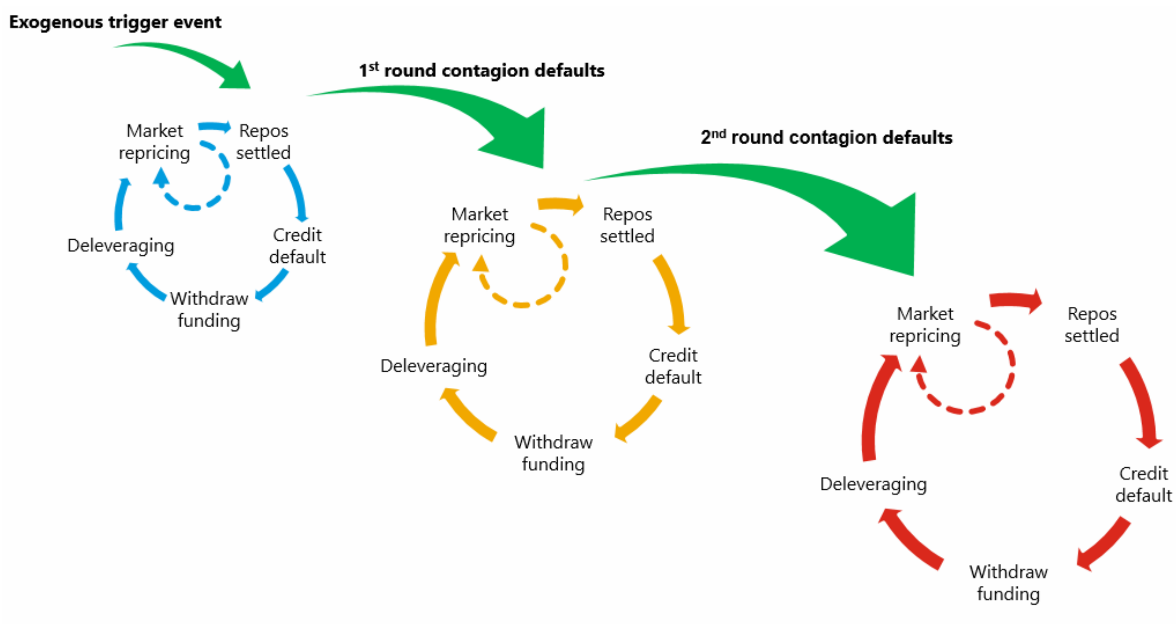
    vii. The solvency and liquidity positions of the banks are reevaluated to determine whether the contagion has caused additional defaults in the network;

- If there are new defaults, the exercise iterates to a new round and the steps i-vii above are repeated. The algorithm terminates when there are no new defaults in a given round.

30. It is important to note that while all nodes in the network are allowed to trigger an idiosyncratic shock, only the active nodes – systemic banks, non-systemic banks and MCIs – in

the core network are allowed to transmit the shock further per data limitations. All the other nodes are therefore considered passive nodes and, for them, the losses are quantified only as absolute amounts – not in terms of lower capital ratios.

Figure 7. Denmark: Contagion Cycle: Rounds and Loops



C. Calibrating Model Parameters

31. Model parameters are calibrated at the highest level of granularity possible based on bank-specific and, to the extent possible, exposure-specific data. This section of the note covers the relevant calculations and, where applicable, assumptions. Further technical details and descriptive statistics on parameter values can be found in Appendix II.

Loss-given-default (λ_{ij}^{k})

32. The estimated loss-given-default rate used in the analysis depends on the type of instrument:

- For loans, deposits, reverse repos and other claims: the loss-given-default is calculated as the allocated value of the protection to the exposure as reported by the credit institution to the credit register in per cent of the exposure amount. The allocated value of the protection is defined as the maximum amount of the protection value that can be considered as credit protection for the instrument following the collateral allocation principles used by the credit institution for internal risk management purposes. There is no requirement that the scope of protection items is aligned with the protection items eligible for credit risk mitigation in accordance with the CRR.

- For covered bonds and other debt securities: the loss-given-default is updated dynamically in the repricing module based on the distance-to-default from the current state.

- For equity and unlisted shares: the loss-given-default is assumed to be 100 percent.

Modified Duration (μ_{ij}^{k})

33. **The modified duration is defined for covered bonds and other debt securities (other bonds) and is used in the repricing module in the model.** It is available for each security and the data included in the model equals the average weighted by the size of the exposures. It is defined as the effect that a 100-basis-point change in interest rates will have on the price of a bond calculated as:

$$Modified\ Duration = \frac{Macauley\ Duration}{(1+{YTM}/{n})},$$

where: *YTM* = Yield To Maturity and *n* = number of coupon periods per year

34. **For Danish callable covered bonds, the option adjusted modified duration is used.** This includes the price behavior of a callable bond that will differ from a non-callable bond due to negative convexity when the bond's price exceeds 100.

Funding Shortfall (ρ_{ij}^{k})

35. **The funding shortfall refers to the portion of withdrawn funding that is assumed not to be rolled over when the entity providing the funding defaults (or gets into distress).** It is calibrated at exposure level by first determining the difference between the reference date (September 30, 2019) and the maturity date of each exposure. The exposures are then divided into maturity buckets by type of exposure with two alternative thresholds for short-term liabilities:

- Exposures with maturity within the next month.

- Exposures with maturity within the next three months

36. **The first maturity threshold is consistent with the Liquidity Coverage Ratio, LCR which assumes a 30-day liquidity distress scenario, and the other threshold is used for testing sensitivity to liquidity distresses over a longer period.**

Default Threshold ($c_{i,min}$)

37. **Default threshold is based on CET1 definition of regulatory capital, with minimum ratio plus the pillar 2 adjustments setting the threshold.** Alternatively, for sensitivity analysis, a higher threshold that includes the additional capital conservation, counter cyclical and SIFI buffers, is also used.

Liquidity Surplus (γ_i)

38. Liquidity surplus is calculated as the stock of HQLA in excess of net liquidity outflows (NLO) over a 30-day liquidity distress scenario. Both HQLA and NLO are reported on Liquidity Coverage Ratio templates (C.72.00-C.76.00).

Liquidity Constraint (θ_i)

39. The pool of marketable securities sets an upper boundary, hence liquidity constraint, to how much a bank has its disposable to deleverage. It is calibrated as the total amount of unencumbered non-central bank eligible assets reported in Asset Encumbrance templates (F.32.01).

Discount Rate (δ_i)

40. Discount rate used in fire sale is estimated for each bank based on the portfolio of its assets classified under unencumbered non-central bank eligible assets weighted by relevant haircuts. Haircut rates for each asset class is based on ECB guidelines on haircuts after applying a lower bound haircut, which is the highest haircut used for the respective central bank eligible instruments.

Capital-to-rating Conversion (g)

41. Rating in this model is solely a function of issuer's capital and therefore the corresponding changes in yield spreads due to rating downgrades is purely a credit spread. The capital ratio is mapped to a rating category based on a methodology used by credit rating agencies (see Figure 8).[9] Dynamic assignment of rating categories is a function of a bank's capital adequacy, $c_{j,t}$, and the general macro profile of the country, M_t, at time t. The macro profile used for the rating conversion is independent of the scenarios used in other stress-testing exercises and is akin to baseline credit assessment. It reflects sovereign risks (both structural and cyclical), credit and funding conditions and industry structure and is mapped on a scale of very weak minus (14) to very strong plus (0), with moderate (7) in the middle. For the main exercise, the macro profile is assumed to be moderate. However, the sensitivity is tested to more and less strict conditions.

Rating Migration Matrix (f)

42. The changes in bond yield spreads is calibrated using the results of an empirical study conducted by Hull et al. (2005) based on historical data on bond yield spreads and credit ratings (see Figure 8). After interpolating the yield spreads for the full tier of rating categories, a migration matrix is constructed to map changes in rating categories to changes in yield spreads. The mapping accounts for the uplift buffer of covered bonds by issuer. Therefore, this migration matrix

[9] See "Rating Methodology" published by Moody's Investors Services (2019).

is formulated as a function of previous rating, current rating and the instrument type. The resulting changes in yield spreads are expressed in basis points.

Figure 8. Denmark: Calibration of Rating Conversion and Migration Matrix

	Moody's		CoMap	Hull et al		CoMap
	CET1<	Rating	Numeric	Rating	Yield spread	Cubic spline
Prime	100	aaa	1	Aaa	83	83
High grade	28	aa1	2	...	...	85
	26	aa2	3	Aa	90	90
	24	aa3	4	...	...	98
Upper medium grade	22	a1	5	...	...	108
	20	a2	6	A	120	120
	18	a3	7	...	...	134
Lower medium grade	16	baa1	8	...	...	154
	15	baa2	9	Baa	186	186
	13	baa3	10	...	...	233
Non-investment grade	12	ba1	11	...	...	289
	11	ba2	12	Ba	347	347
	10	ba3	13	...	...	405
Highly speculative	9	b1	14	...	...	477
	8	b2	15	B	585	585
	7	b3	16	...	...	748
Substantial risks	6	caa1	17	...	...	987
	5	caa2	18	Caa	1321	1321
	4.5	caa3	19	...	...	1771
Extremely speculative	0	ca	20	...	...	2357

Sources: Moody's Investors Services (2019), Hull et al., IMF staff calculations.

D. Results

43. The simulation exercise consists of a series of idiosyncratic shocks, where the default of each entity is triggered iteratively. This exercise generates two main outputs: number of defaults caused by the trigger event and losses incurred by each entity in the network in each simulation. The traced losses are used to create the following indices customized for the core network:

- Contagion index (CIcore) captures the contagion to the core network induced in each simulation triggered by node i by taking a weighted average of all core banks losses in percent of their capital:

$$CIcore_i = 100 * \sum_{j \in \mathcal{C}} \frac{L_{j,i}}{c_j}\ , where\ L_{j,i}\ is\ j's\ losses\ induced\ by\ i\ and\ c_j\ is\ j's\ capital$$

- Vulnerability index (VIcore) of each entity is constructed as the average loss experienced by entity i over the number of simulations induced by other entities in the core network:

$$VIcore_i = 100 * \frac{\sum_{j \in \mathcal{C}} L_{i,j}}{N_{core} * c_i}\ , where\ N_{core}\ is\ the\ number\ of\ core\ entities;\ L_{i,j}\ and\ c_i\ as\ before$$

$$VI_i = 100 * \frac{\sum_{j \in \mathcal{F}} L_{i,j}}{N_{\mathcal{F}} * c_i}\ , where\ N_{\mathcal{F}}\ is\ the\ number\ all\ entities;\ L_{i,j}\ and\ c_i\ as\ before$$

44. CIcore can be used to compare nodes in the network in terms of how much contagion each node causes to the core system if it was to experience severe distress (a tail event). VIcore is used to gauge fragility of banks to idiosyncratic shocks coming from within the core network and banks that on average incur greater losses due to their exposures are deemed more vulnerable to the banking system. The average losses take into account both the magnitude of a bank's losses (in response to each default event) and the frequency with which it experiences losses (by treating each default with equal probability). The overall VI, on the other hand, gauges banks' vulnerability to shocks from the full network and can help determine vulnerabilities to both inside and outside entities.

45. Furthermore, the contagion and vulnerability indicators are decomposed into sub-indices. These sub-indices provide deeper insights into how an initial shock gets amplified, which type of entities can transmit larger shocks or are subject to greater losses and what instruments play a central role in transmitting the shock. The decomposition is implemented along several dimensions according to:

- the nature of risk transmission (credit, funding and market repricing);
- the entity type (systemic, non-systemic and MCI); and
- the instrument type (loans, covered bonds, unlisted shares, etc.).

Appraisal of Contagion Risks

46. The analysis reveals that Danish credit institutions are mostly exposed to shocks from within the banking system.[10]

- Half of the top 20 most contagious nodes are Danish credit institutions, highlighting the highly interconnected nature of the banking system (Figure 9, top panel). Of these, five are MCIs, three are systemic banks and the other two are non-systemic banks.
- MCIs are a key source of outward spillovers. They induce the highest levels of contagion losses, both collectively as a group and individually with two MCIs ranking in the top three. A closer inspection points to unlisted shares (reflecting complex group structures) accounting for the majority of these losses, followed by covered bond exposures as another significant source.

[10] The analysis considers financial institutions individually (and not as groups).

- Systemic banks, while generating far less contagion losses, transmit the shock through a more diverse set of instruments, with covered bonds having the largest contribution.

- More broadly, banking sectors at country level from Nordic region and euro area may generate significant spillovers. In fact, the highest contagion index (12.3 percent) in the exercise is generated mainly through interbank loans and deposits when the default of the entire banking system of a euro area member state is used as the trigger event.

- In terms of channels, contagion is transmitted predominantly through credit losses. Cascade effects owing to the repricing channel come into play more visibly under two simulations, where the default of one MCI and one non-systemic bank respectively is triggered (Figure 9, top left panel). Mainly one other non-systemic bank is affected by losses through the repricing channel (Figure 9, middle left panel). The losses generated through the funding channel seem to be very limited since banks' liquidity buffers allow them to withstand large funding shortfalls due to counterparty withdrawals in most cases.

Identifying Vulnerabilities in the System

47. Focusing on the fragilities, the vulnerability indices of all Danish credit institutions are ranked and grouped together to further decompose into underlying drivers.

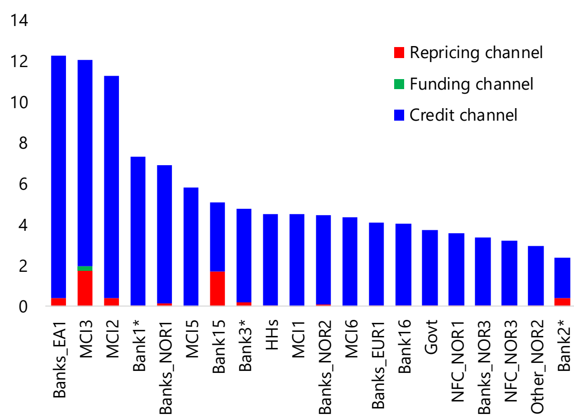
- Systemic banks are more vulnerable to shocks from within the banking system although the average vulnerability indices of MCIs and non-systemic banks do not differ significantly (Figure 9, middle panel). In fact, the highest vulnerability index is associated with an MCI, which incurs average losses of about 4.5 percent (VIcore) of its capital from failures in the core network. Overall, covered bonds contribute the largest share to the core network's vulnerabilities, followed closely by unlisted shares. As for the considerable deposit-related losses experienced by MCIs, this is partly due to a temporary spike in their deposits observed on September 30, 2019 (see Caveats section for more details).
- More generally, considering the full network of exposures, systemic banks face the highest inward spillover losses (Figure 9, lower panel). The significantly lower (about one to ten) overall vulnerability indices in comparison to core vulnerability indices can be explained by the dilutive effect of increasing the network size from 21 to 1005 nodes. When the universe of potential exposures is expanded, there is a disproportional rise in the relative ranking of systemic banks with their average overall vulnerability index at three times higher than that of MCIs'.
- A deeper dive reveals, from outside the core network, significant portion of systemic and non-systemic banks' losses can be attributed to loans, deposits and other claims. These losses are likely to be associated with credit exposures to households and NFCs and the residual group "Other", including OFIs as well as interbank deposits held at non-core,

including foreign, credit institutions.[11] Given that MCIs have some of the largest exposures to households and NFCs, the reason that these do not create contagion losses is due to the extremely low loss-given-default values associated with these exposures. Therefore, while MCIs face similar contagion losses from within the core network, they are much less vulnerable to shocks from outside the banking system unless there is a significant drop in real estate prices impacting the collateral value of their exposures, which would put upward pressure on the loss-given-default calculations..

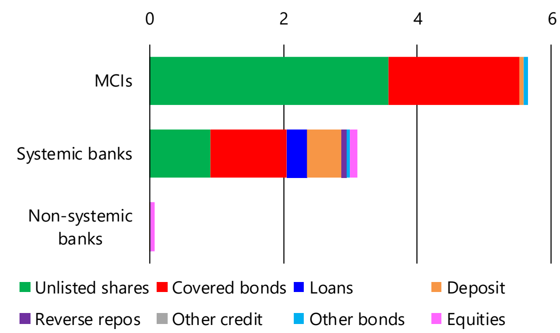
[11] In this Technical Note, OFI is used to describe all financial intermediaries other than credit institutions, pension funds, insurance companies, and investment funds, which are grouped separately

Figure 9. Denmark: Contagion Analysis: Main Results

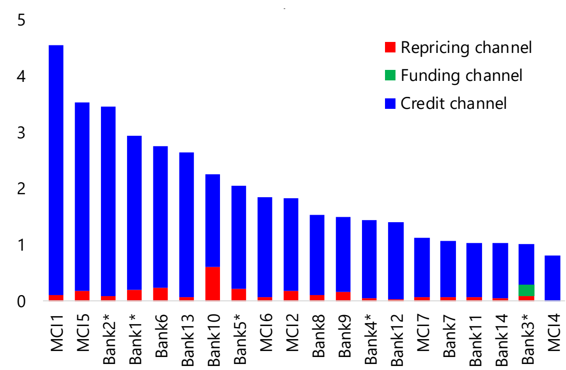
Core Contagion Index



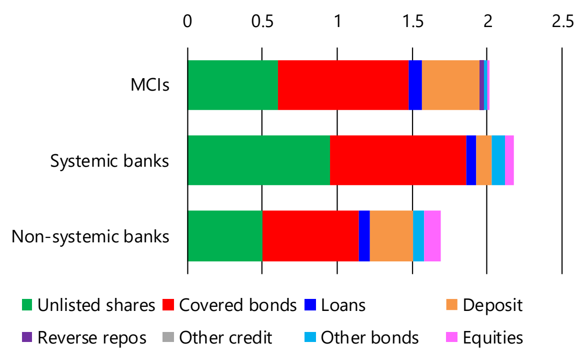
Core Contagion Index by Layer



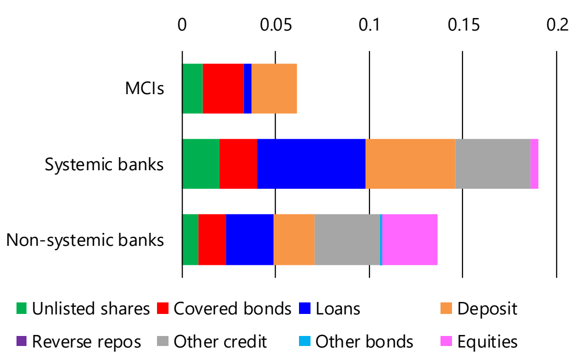
Core Vulnerability Index



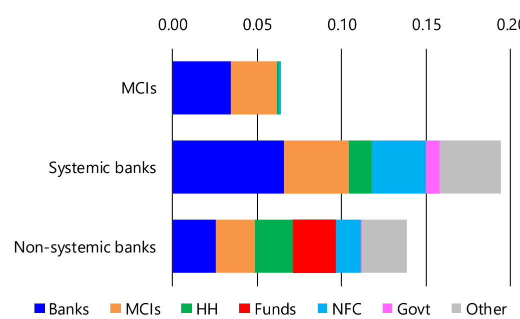
Core Vulnerability Index by Layer



Overall Vulnerability Index by Layer



Overall Vulnerability Index by Source



Source: Supervisory data; IMF staff calculations.

Notes: Banks with * indicate systemic banks. Contagion index (CI) is the average losses to the core network comprising 21 credit institutions normalized by their capital. For example, the hypothetical default of the most contagious individual entity, MCI3, results in the average losses to the other 20 entities of around 12 percent of their capital. The most vulnerable bank as measured by Vulnerability Index (VI), also MC1, incurs average losses of about 4.5 percent of its capital across all independent simulations, following the hypothetical default of each core entity in the network. Households are aggregated at sector level and a default ratio of 20 percent is assumed, which is an extreme figure given the historical data. Overall vulnerability index is the average losses with respect to the complete set of simulations for the full network, whereas, core vulnerability index focuses on the degree of vulnerability associated with shocks specifically from within the banking system, the core network (for detailed explanation of indices, see the beginning of the Results section).

Cascade Effects and Risk Map

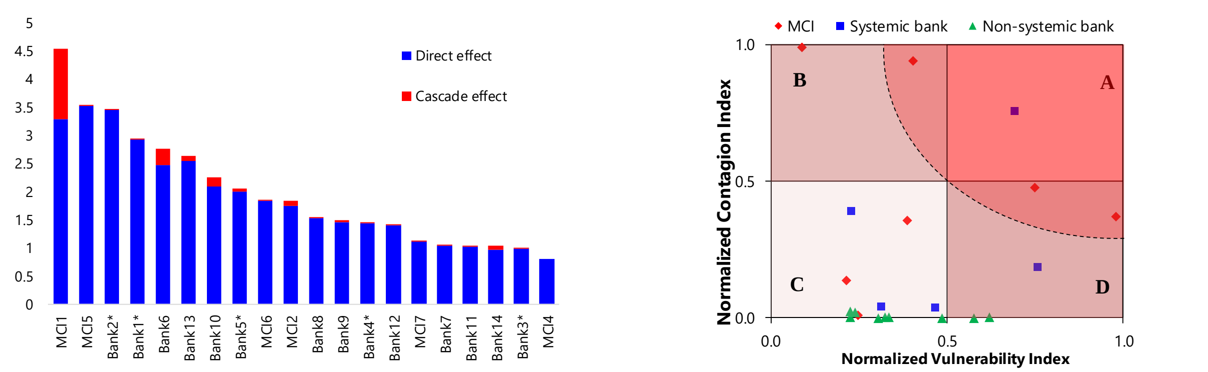
48. This framework differentiates between two types of cascade effects associated with: (i) repricing channel, effectively, captures market reaction to losses from credit and funding channels and moves in a gradual way; and (ii) knock-on effects when a counterpart incurs enough losses to reach its default threshold and subsequently causes contagion losses to others. As discussed earlier, the amplified losses through repricing channel are limited, which can be partly attributed to the characteristics of the underlying data. Covered bonds, which make up a significant portion of cross-held securities in the core network, have shorter durations (see Appendix Figure 2 of Appendix II) while also benefiting from very high initial credit ratings (i.e. AAA) and uplift buffers. These culminate in overall relatively small valuation losses that are solely due to credit spreads[12] The knock-on effects and losses in subsequent rounds of failures are similarly small (Figure 10). This result is directly related to a very low number of contagion defaults observed in this exercise. These defaults are either associated with smaller non-systemic banks or between entities within the same group, resulting in subdued losses in the subsequent round.

49. Having said that, the Risk Map identifies four entities that are relatively on the higher scale of both contagion and vulnerability indices (Figure 10). This is the critical zone from an interconnectedness perspective as these entities are, in relative terms, not only more exposed to contagion risks (inward spillovers) but they can amplify these spillovers by creating further contagion in the system.

Figure 10. Denmark: Contagion Analysis: Cascade Effects and Risk Map

Core Vulnerability Index by Effect

Risk Map



Source: Supervisory data; IMF staff calculations.

Notes: Banks with * indicate systemic banks. Risk Map plots the normalized CI and VI (between 0 and 1) of each entity indicating where the tipping points might be in the network. For example, all the entities in the dark-shaded quadrant are relatively both more contagious and and more vulnerable than the rest in the network

[12] There is also a modeling aspect for this result, which is explained in detail in the Caveats section.

E. Robustness

50. This section tests the sensitivity of the main findings to a range of parameter assumptions and calibrations.

Rating Conversion and Migration

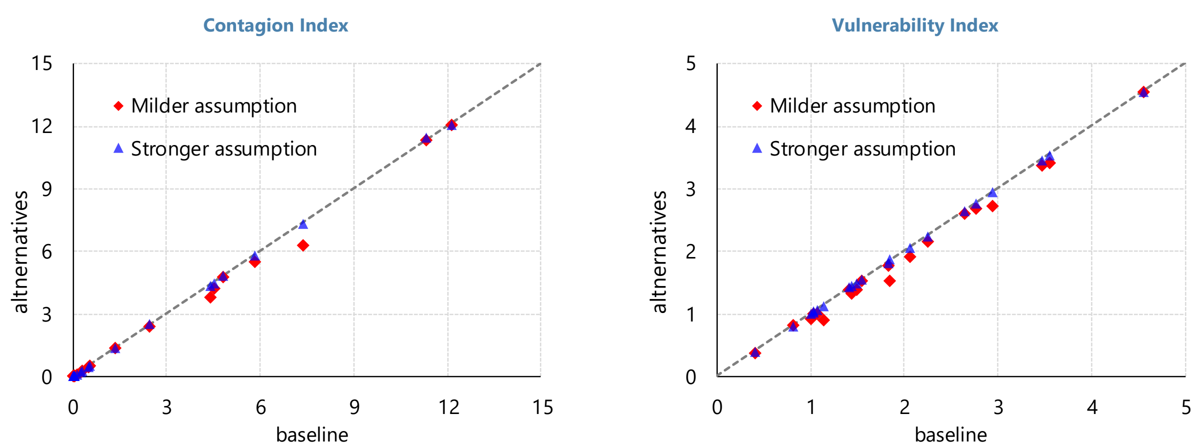
51. In the main exercise, the baseline calibration assumed the assessment of the macro environment to be in the moderate category (see Methodology section). The first sensitivity analysis tests this assumption against two alternatives:

i. Stronger assumption based on "weak" macro profile. Effectively, a given capital adequacy ratio would correspond to a lower credit rating, and thus the same decline in the ratio would provoke a larger yield change in the issuer's securities.

ii. Milder assumption based on "strong" macro profile. This would translate to a higher credit rating for a given capital adequacy ratio, and consequently would lead to smaller yield changes

52. There is little sensitivity to assumptions around determining market reaction to changes in banks' capital adequacy. As can be observed in Figure 11, the alternative assumptions do not generate any material variation in the contagion and vulnerability indices. More importantly, the ranking of entities in terms of contagiousness and vulnerability hardly change. These results can be explained by the small share of contagion losses associated with market pricing mechanism.

Figure 11. Denmark: Sensitivity to Rating Conversion and Migration Matrix

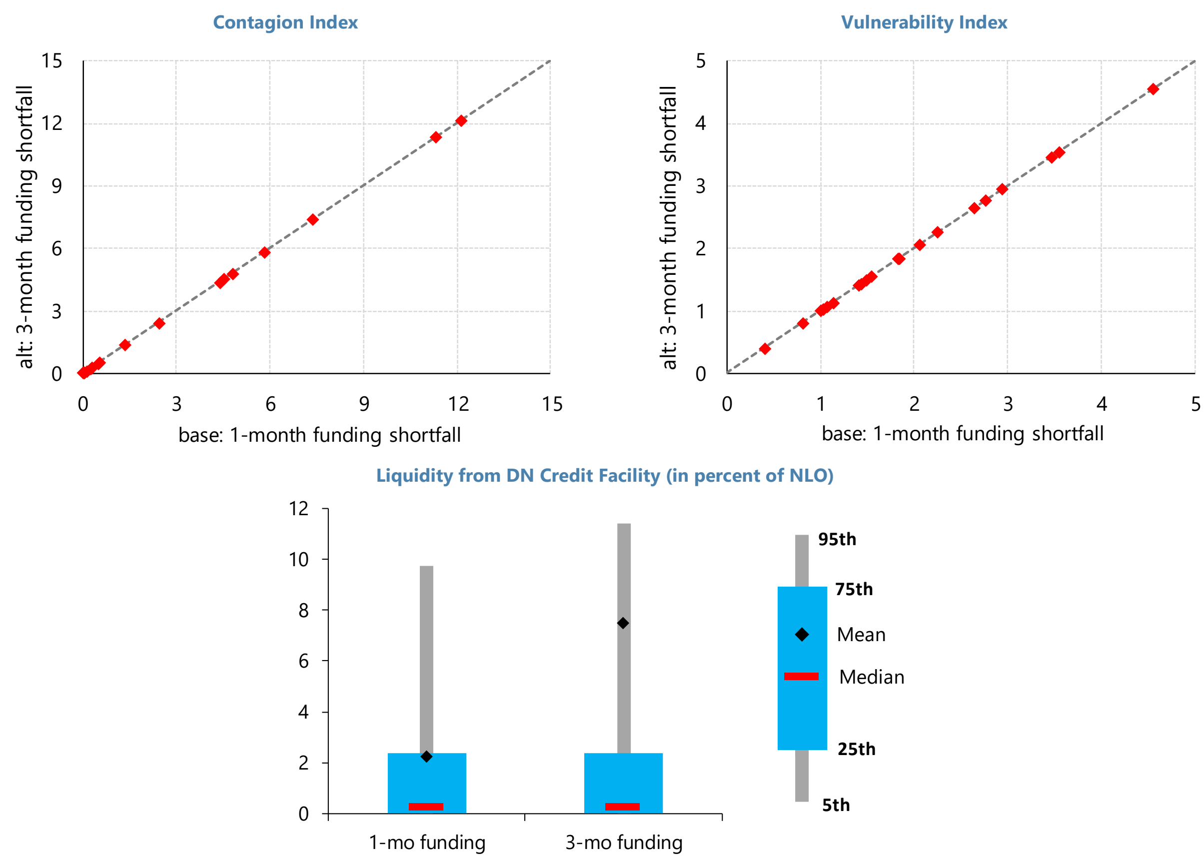


Source: Supervisory data; IMF staff calculations.

Funding Shortfall Ratio

53. For the funding shortfall ratio, the alternative assumption raises the maturity related to the calculation of short-term funding from one month to three months. Effectively, this more stringent assumption should result in larger funding withdrawals and therefore increase the amount of fire-sale losses. This sensitivity test shows that there are no additional contagion losses when the funding shortfall amount is raised (Figure 12). This result can be attributed to banks' ability to use liquidity buffers to withstand further tightening in funding. This is illustrated by the average increase in the amount of liquidity received through CB credit facility.

Figure 12. Denmark: Sensitivity to Funding Shortfall Ratio



Source: Supervisory data; IMF staff calculations.

Default Ratio for Households and NFCs

54. Since the households and NFCs are aggregated at sector and industry level, the main exercise used a "default ratio" parameter to represent the portion of these sectors that would default on their loans. It is important to test the sensitivity of the main findings to this parameter as banks and MCIs have significant exposures to these sectors.

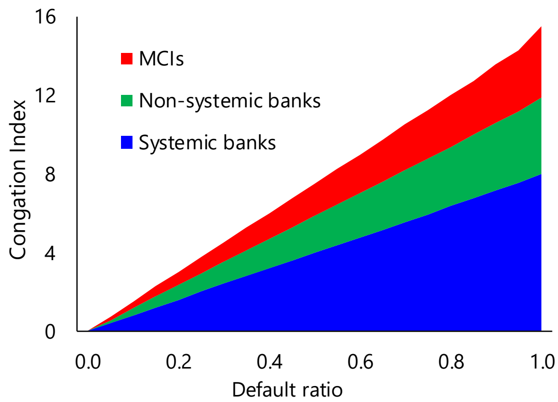
- In this sensitivity analysis, the default ratio is increased in 5 percentage point increments up to 100 percentage points to determine whether any tipping points exist in a wide range creating significant non-linearities. Since the default rate and loss-given-default parameters enter multiplicatively to determine the losses from an exposure, Figure 13 (bottom panel) can be used to determine the set of combinations corresponding to the same loss rate on the exposure.

- For example, if a bank's LGD for loans to the household sector is 2 percent, a 100 percent default rate assumption would mean 2 percent losses on this exposure. This share of losses corresponds to 50 percent default ratio if LGD went up to 4 percent or 10 percent default ratio if LGD moved to 20 percent, which would be a more realistic, albeit a very severe, combination. Such combination could underlie a scenario, where a share of households on a bank's portfolio are defaulting on their loans at the same time as those particular loans being defaulted upon are associated with declining collateral values, impacting the bank's recovery ratio.

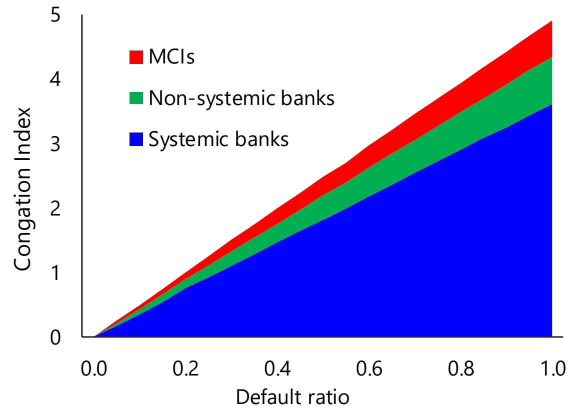
55. Figure 13 shows that, respectively, Household and Real Estate sectors' contagion losses are almost entirely linear with respect to default rate. There are a few kinks on these graphs reflecting defaults of individual entities as they fail. However, the slope of the curves remain stable throughout indicating that individual failures do not lead to substantial cascade effects. This implies that there are no tipping points that would increase the speed and extent of a trigger event.

Figure 13. Denmark: Sensitivity to Default Ratio

Household's Contagion Index



Real Estate Sector's Contagion Index



Default Rate and LGD Combinations

Loss-given-default rate (%) \ Default Rate (%)	5	10	15	20	25	30	40	50	60	70	80	90	100
1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
2	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
3	0.2	0.3	0.5	0.6	0.8	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
4	0.2	0.4	0.6	0.8	1.0	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
5	0.3	0.5	0.8	1.0	1.3	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
10	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
15	0.8	1.5	2.3	3.0	3.8	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0
20	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0
25	1.3	2.5	3.8	5.0	6.3	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
30	1.5	3.0	4.5	6.0	7.5	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0
35	1.8	3.5	5.3	7.0	8.8	10.5	14.0	17.5	21.0	24.5	28.0	31.5	35.0
40	2.0	4.0	6.0	8.0	10.0	12.0	16.0	20.0	24.0	28.0	32.0	36.0	40.0

Source: Supervisory data; IMF staff calculations.

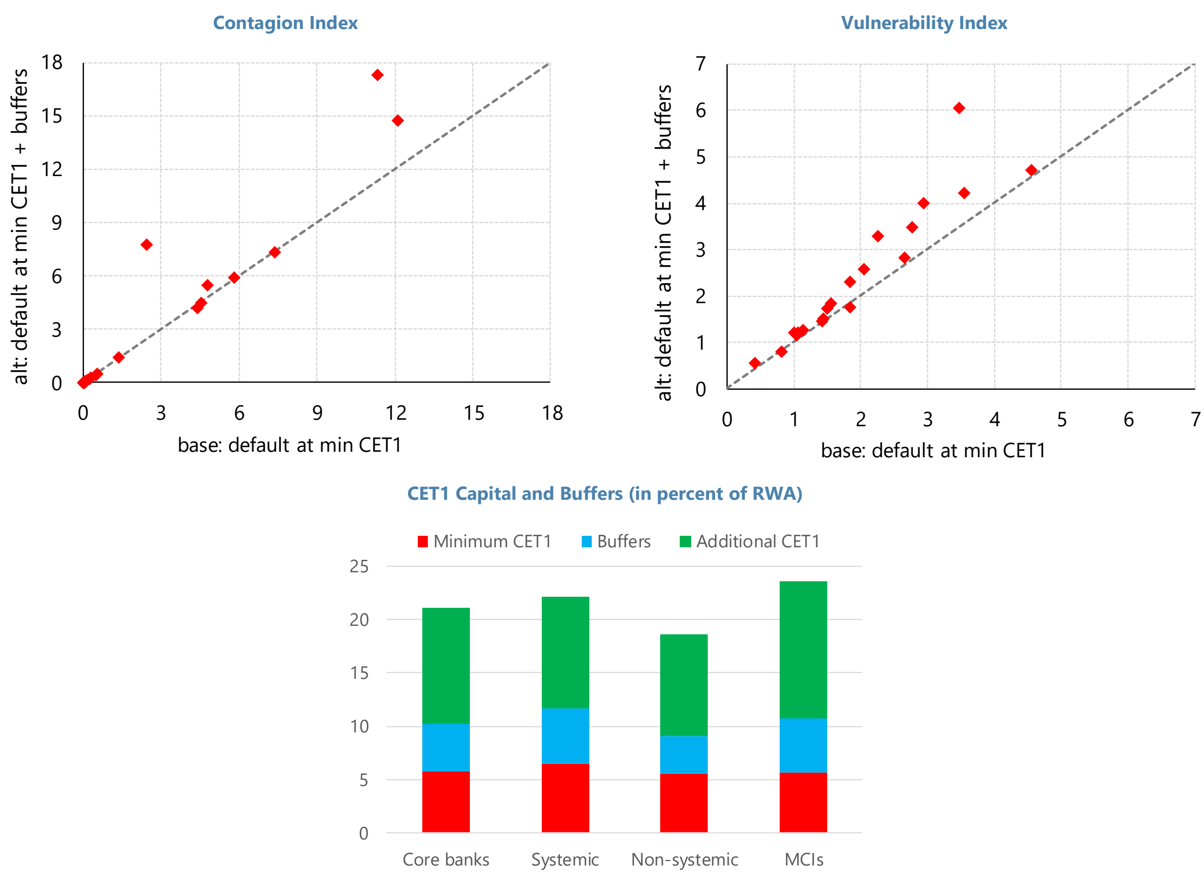
Default Threshold

56. **As the last sensitivity check, the default threshold is raised from minimum CET1 to include all regulatory buffers.** CIs and MCIs are subject to three regulatory buffer requirements: the capital conservation buffer (2.5 pct), the SIFI buffer (0-3 pct) and the countercyclical capital buffer (1-1.2 pct). Breaching the buffer requirements does not lead to default, but a number of restrictions will be imposed on the CIs and MCIs, e.g. in relation to dividend payments and interest payments on hybrid capital instruments. This can weaken the entities' access to external funding in the financial markets at a time when funding might already be difficult to obtain. To reflect the heterogeneity across banks, entity-specific buffer levels are used (Figure 14, bottom panel).

57. **The results of this sensitivity test show that not only overall contagion losses experienced by each bank increase but also the ranking of entities change noticeably (Figure 14, top panel).** The changes in terms of the entities that cause the contagion are a lot fewer but

more significant. For example, an entity which was previously ranked in the lower half of the graph, becomes one of the top 3 with its contagion index almost tripling.

Figure 14. Denmark: Sensitivity to Default Threshold



Source: Supervisory data; IMF staff calculations.

58. **Overall, it can be argued that the findings are broadly robust to a number of alternative assumptions and calibrations.** There are no significant non-linearities observed to incremental changes with the exception of default threshold. In this respect, setting the threshold in line with bank-specific required buffers leads to significant changes both in absolute and relative contagion losses.

F. Caveats

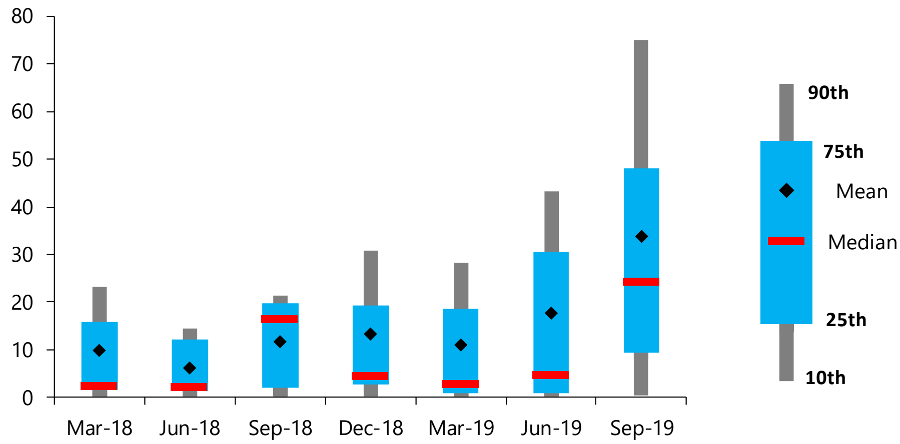
59. **The repricing channel in the contagion model captures changes in market valuation only due to credit spreads, which is driven by each MCI/bank's capitalization.** There could be additional contagion due to market liquidity shocks driven by selling pressures in particular asset markets (e.g. covered bonds). This additional contagion through market liquidity wasn't incorporated in the contagion model (due to data limitations to calibrate

relevant model parameters) and would have likely increased the overall contagion in the system as well as the contribution of repricing channel versus other channels.

60. The data point used to conduct the exercise (September 30, 2019) presents some peculiar characteristics. On this specific day, MCIs experienced a very high amount of liquidity due to a large number of customers refinancing their mortgages (Figure 15). On this specific date, the refinancing of mortgages were at a historically high level, increasing the contribution of these large deposit transactions to contagion losses. The received liquidity was temporary in nature as it was used to pay investors on the subsequent payment date (October 1, 2019). Therefore, to the extent that such exposures were short-natured and unusual, the losses experienced by MCIs due to deposit exposures could have been overestimated with asymmetric distribution across entities.

Figure 15. Denmark: Sudden Rise in MCI's Deposits

(in percent of total assets)



Sources: Danmarks Nationalbank, IMF staff calculations.

61. Danish OFIs, investment funds, governmental entities are aggregated and treated as entities representing their respective sector. This is also the case for all cross-border exposures, which are aggregated at sector level for each country. Consequently, the idiosyncratic shock, that assumes the default of one of these nodes, translates to a sector-level shock in each of these countries. Shocks to these entities are currently not parametrized using a default rate. Therefore, a trigger shock implies the default of the entire sector.

62. In this exercise, financial entities are considered at solo level. This choice reflects the reporting level of the credit register and allows us to distinguish entities with different business models and subject to different regulatory requirements. It is important to keep in mind, that the three largest Danish SIFIs are all groups, consisting of a CI, an MCI and further subsidiaries such as pension companies or MCIs. This group structure is heavily reflected in the results for the idiosyncratic shocks, where a mother company naturally incurs large losses through ownership of unlisted shares in its subsidiary, when the subsidiary is used as the trigger default. For the core network, around 90 percent of unlisted shares represent intra-group ownership while the same ratio is approximately 75 percent when the unlisted shares in the full network are considered.

63. In terms of coverage, a key limitation is that the analysis was largely based on reporting provided by banks on their exposures. Securities data was used to complement some of the data gaps especially with respect to common asset holdings. However, significant data gaps remain, for example, on the non-bank wholesale funding for banks that could be a significant transmission channel for concentrated positions. Furthermore, limited information on the foreign ownership of securities issued by Danish entities as well as the unavailability of data on balance sheets of non-bank and foreign financial entities only allow for partial analysis of outward spillovers from Danish banking system. Given that there could be significant feedback loops both from within Danish financial system and other Nordic and EA banking sectors to which Danish banks have material exposures, the contagion risks could be underestimated.

CONCLUSION

64. In summary, the results suggest that the risk of contagion is strongest from within the banking system given the intra-group exposures and cross-ownership of covered bonds. Accordingly, MCIs are a key source of potential contagion in the financial system. The analysis points to the higher vulnerability index of systemic banks compared to MCIs and non-systemic banks in this framework. Their vulnerability originates both from within the banking system but more importantly from the other relevant sectors of the economy. The results also highlight the primary role of credit channel in propagating contagion losses, and points to Nordic region and EA banking systems as significant sources of cross-border spillovers to Denmark.

65. As discussed in the modeling and caveat sections, certain data limitations prevent expanding the scope of the interconnectedness and contagion risk analysis to system-wide level. On the basis of the covered bond market that is deeply entrenched with its long history in Danish economy, it is critical to map all the interlinkages and model the transmission through different financial intermediaries and the real sector. Therefore, closing the data gaps and developing a more comprehensive analytical framework to study contagion risks would further enhance the monitoring and assessment of systemic risks to and from the financial system in Denmark. In addition, the overall macroprudential stress-testing framework would further be strengthened by incorporating these contagion effects across financial institutions.

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Appendix I. Stress Testing Matrix (STeM)

Contagion Risk Analysis		
Domain	**Assumption**	
1. Institutional Perimeter	Institutions included	Active nodes: • Systemic banks: Danske Bank, Jyske Bank, Nykredit Bank, Sydbank, Spar Nord Bank • Non-systemic banks: Arbejdernes Landsbank, Ringkjobing Landbobank, Sk. Kronjylland, Sk. Sjaelland-Fyn, Laan & Spar, Vestjysk Bank, Sk. Vendsyssel, Jutlander Bank, Den Jyske Sk. • Mortgage credit institutions: Nykredit Realkredit, Realkredit Danmark, Totalkredit, Nordea Kredit, Jyske Kredit, DLR Kredit, LR Realkredit Passive nodes: • Danish financial entities at individual level: 109 "Group 3" banks and branches of foreign banks, 103 life and non-life insurers, 41 pension funds; • Danish sectors at aggregate level: investment funds, other financial institutions, households, NFCs by industry • Cross-border counterparties aggregated at sector level by country: credit institutions, pension funds, insurance companies, investment funds, other financial institutions, households, NFCs, governments, and ROW.
	Market share	• Active nodes account for 86 percent of the total assets of the Danish banking system.
	Data and baseline date	• Sources: Credit register, securities database, and supervisory COREP, FINREP, and national reporting templates. • Single datapoint: September 30, 2019.
2. Channels of Risk Propagation	Methodology	• Application of CoMap framework (Covi, Gorpe and Kok, 2019), with extensions to model multi-layer contagion through 8 different instrument types (loans, deposits, reverse repos, other claims, covered bonds, other bonds, equities and unlisted shares) and incorporate MCIs as active nodes.
	Risks/factors assessed	• Credit default channel. • Funding withdrawal channel. • Market repricing channel for securities.
3. Tail Shocks	Scenario analysis	• Idiosyncratic shocks: hypothetical failure of each entity as a potential trigger event.
	Sensitivity analysis	• Sensitivity to parameter calibrations along several directions: default threshold, funding shortfall maturity buckets, rating conversion and migration, default ratio for households and NFCs.
4. Reporting Form for Results	Output presentation	• Number of cascade defaults. • Contagion losses induced (contagion index) and experienced (vulnerability index) by each node. • Decomposition of losses by layer (instrument type) and entity types.

Appendix II. Multi-layer Contagion Mapping (CoMap) Model–Data Calibration

Data Assumptions

- *LGD:* In six repo transactions no protection is reported for the loans. This implies an incorrect LGD and the LGD is adjusted to the average LGD for repos for the same creditor. For one intragroup exposure the LGD is set to 0 as it relates to a business model issue.

- *HQLA:* Two MCIs that are part of the same group do not report liquidity data separately (because they have a joint liquidity function). The HQLA reported jointly for the two entities has been distributed to each of them based on their fraction of total loans.

- *Modified Duration:* For covered bonds with modified duration less than zero the modified duration is set to 0. Some debt securities (2.7 percent of the total outstanding amount of debt securities) cannot be enriched with data from the securities statistics and the modified duration for these securities is set to 1. This limits the repricing module for these securities. For covered bonds this relates to 0.1 percent of the total outstanding amount of covered bonds, and for other debt securities this relates to 7 percent of the total outstanding amount of these securities.

- *Household and investment fund exposures:* So called "puljeordninger" are assets banks can hold on behalf of their clients. These assets are allocated to the banks' clients based on the reporting of the banks. However, due to a reporting error this allocation cannot be performed for one bank resulting in incorrect exposures of a non-SIFI bank to investment funds.

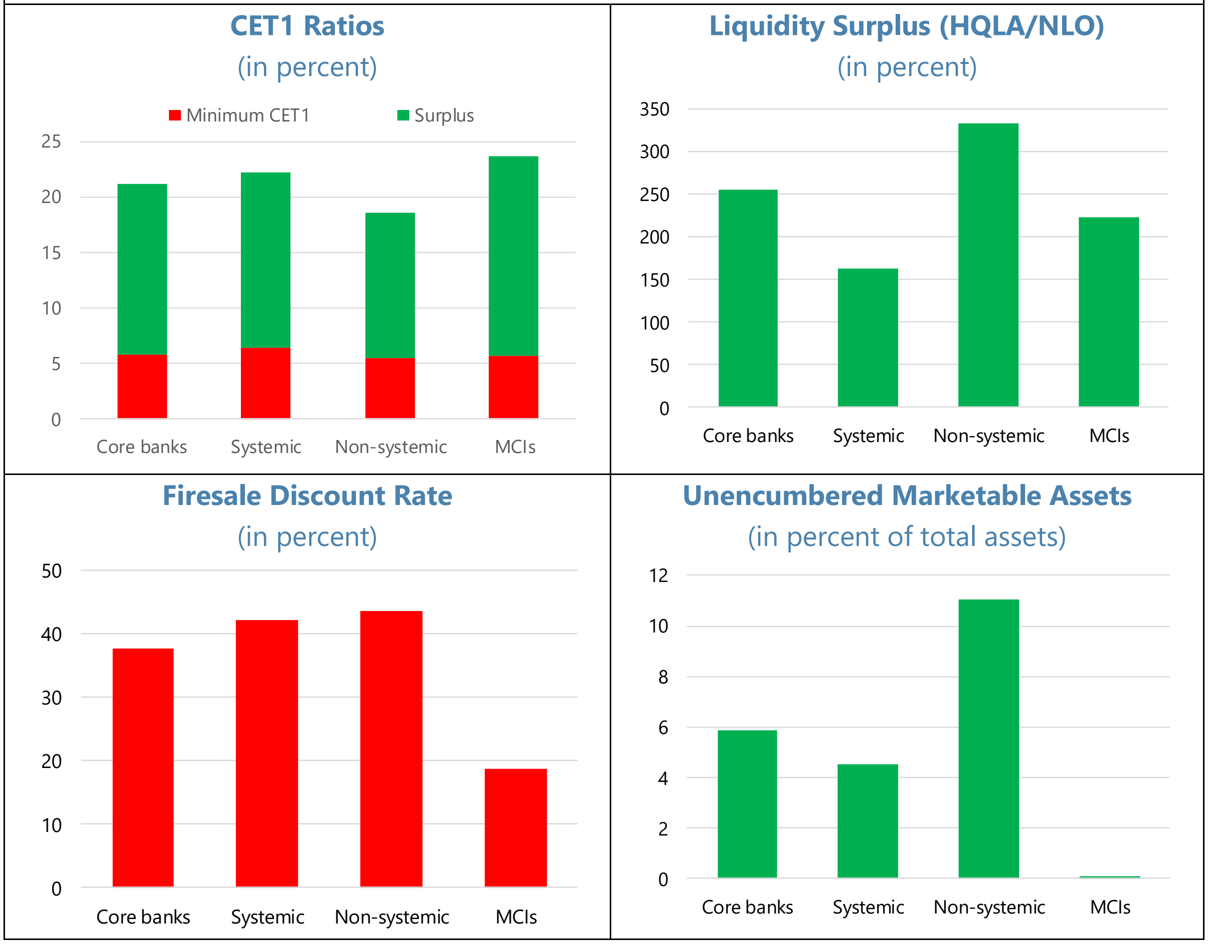
Modeling Assumptions

- *LGD:* Loss-given-default calibration is solely based on protection value underlying each exposure and does not incorporate various other factors that are typically considered for solvency stress-tests, such as credit rating and residence of the issuer/debtor among others.

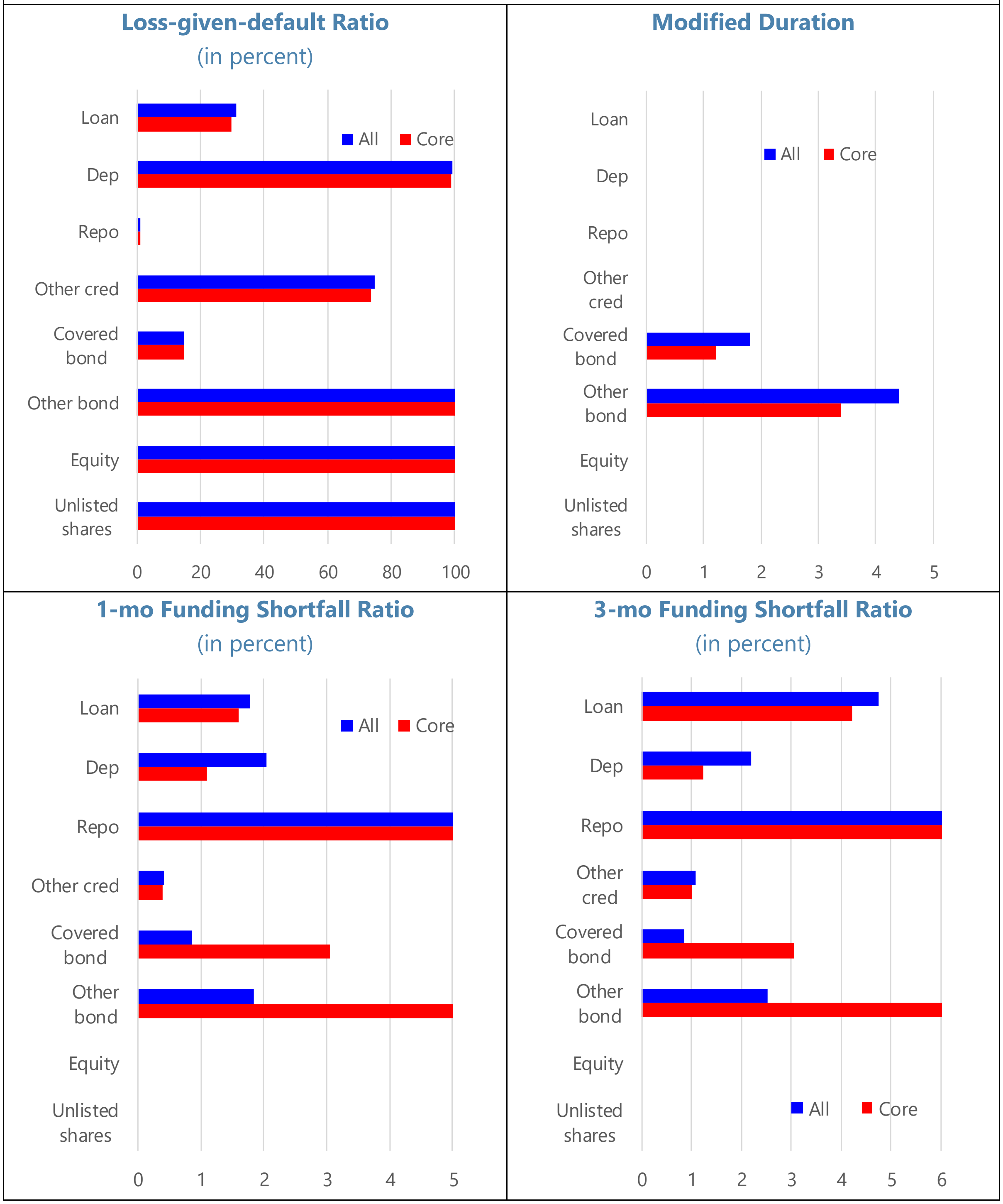
- *Entity level:* The data reported to the securities statistics and credit register are based on institutional level reporting. This means that no information on securities holdings for any foreign branches of the Danish credit institutions are included – however these holdings are minor. In the credit register, data from the largest foreign branches of Danish credit institutions are included and added to the exposures of the relevant credit institution(s).

- *Branches:* Note that in the data, the branches in Denmark of foreign credit institutions are assigned to the Danish banking sector, although it would be more in line with the solo level approach, if they were assigned to the banking sector of the country of the foreign credit institution they belong to.

Appendix Figure 1. Denmark: Entity Level Variables



Appendix Figure 2. Denmark: Exposure Level Variables by Layer



Appendix Figure 3. Denmark: Exposure Level Variables by Entity Type