Staff memo

The Riksbank's method for stress testing banks' capital

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May 2019

S V E R I G E S R I K S B A N K

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Summary

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Since 2006, the Riksbank has used different forms of stress tests to assess the major banks' resilience during periods of financial and economic turbulence. In this publication, we describe how the Riksbank stress tests the banks' capital. The Riksbank does this with consideration of the entire banking system, including the second-round effects that can arise between banks in financial crises. The Riksbank's method for stress testing the banks includes models that are used to estimate credit losses, earnings and second-round effects. The outcome of stress tests is measured in the form of changes in the banking system's capital strength. This publication focuses on the Riksbank's methods for stress tests and the models that form a basis for the method. No outcomes of stress tests will thus be reported in this staff memo. The Riksbank also works on producing alternative stress tests. This primarily involves credit loss models based on more detailed data, such as micro data or supervisory data.

[1] We would like to thank especially David Forsman, Kristian Jönsson and Annette Vissing-Jørgensen for their valuable comments on this staff memo. We would also like to thank colleagues at the Riksbank for useful input. The credit loss model is based on earlier work by Paolo Giordani. The opinions expressed in this document are those of the authors and are not necessarily shared by the Riksbank.

Introduction

Banks, credit risk and earnings

Banks are central actors in both the financial system and society at large. Banks fulfil an important function in society as they can help private persons to borrow for investments for example in housing, and companies can borrow to invest in new machinery or product development. At the same time, companies and private persons can use the banks' services to save for pensions, consumption or future investments. Savings by households and companies make up part of the banks' funding, but banks also obtain funding by issuing certificates and bonds of various types on the capital markets. As one of the banks' main tasks is to provide credits in this manner and, at the same time, channel savings into funding, they become central participants in both the economy at large and the financial system.[2]

A natural part of the banks' lending activities is that they expose themselves to credit risk, which is to say the risk of losses due to a borrower not meeting its financial commitments. When a borrower defaults, credit losses arise, which decreases the bank's profits and impacts its capital. For a bank to be able to manage credit losses, it needs to retain a certain amount of capital in relation to its assets.[3] If the bank's capital decreases to a large extent due to increased credit losses, the bank could face difficulties running its operations and thus risks failing or losing its banking license.

Banks earn their money by charging a higher interest rate on their lending than what they pay on the liabilities with which they fund this lending. This difference is called *net interest income*. Another important source of income for banks is *net fee and commission income*, which is generated by the banks selling services and financial products. Together, these two form the banks' largest source of earnings. However, the banks' earnings are affected by various economic factors and, in periods of financial and real economic turbulence, the banks' profitability can deteriorate. Earnings make up a large part of the banks' resilience, partly because they have to be able to meet the costs of their operations, and partly because they must be able to build up capital during and after crisis periods.

Systemic consequences – banking crises are costly for society

A functioning financial system is a prerequisite for a modern economy to be able to function. Banking crises, and financial crises more generally, are very costly for the financial system and also for society. One example of this is the Swedish banking crisis of the 1990s, when tax money had to be used to support the failing banking system, whereby gross domestic product (GDP) fell heavily and unemployment rose. Another example is the global financial crisis of 2007–2010. The global financial crisis made it obvious that some financial institutions had such global systemic importance that the financial markets could be seriously disrupted by their failure, even across jurisdictions.

There are also structural vulnerabilities in the Swedish financial system today. The Swedish banking system is concentrated to a few systemically important actors with cross-border operations. In addition, the different parts of the financial system are closely interconnected via exposures between financial institutions, both through trading operations and through bilateral loans. This, combined with the banks' central role in the economy, means that problems arising in one institution or on one market quickly can spread through the system and into the real economy.[4]

[2] The Riksbank 2016.
[3] See Almenberg et al. 2017 and Hanson et al. 2011 for a more detailed discussion of why banks need capital and which level of capital is optimal for banks.
[4] The Riksbank 2018.

Why does the Riksbank carry out stress tests?

For many years, the Riksbank has carried out different kinds of stress tests to assess resilience to financial risks and threats in individual banks and in the banking system as a whole. The Riksbank has also continually developed the methods used. The Riksbank does this as part of its task of ensuring that the payment system is secure and efficient. This is because the banks are important participants in the payment system and also play a central role in the financial system. Banking crises can thereby affect both financial stability and the development of the real economy, as well as the implementation of monetary policy. The Riksbank therefore continually analyses how the banking system is developing to discover threats and vulnerabilities at an early stage. The stress tests are part of this work.

The Riksbank can provide liquidity assistance to the banks in a financial crisis. One legal prerequisite for this, however, is that the bank receiving liquidity assistance has enough capital to be able to repay its debts, not only for the time being but also after a longer period of financial stress. Also in this context, stress tests are an important tool for assessing an individual bank's resilience.

What is a stress test?

A stress test is an analytical tool that tests the banks' resilience to financial risks and threats in a hypothetical scenario, for example a deep economic recession and falling asset prices (for example housing prices[5]). Since the global financial crisis of 2007–2010, stress tests in various forms have increased in significance globally.[6] Today, both banks and authorities carry out stress tests to identify risks and vulnerabilities of various kinds.

The European Banking Authority's scenario for stress tests

In 2018, the European Banking Authority (EBA) carried out a stress test of 48 European banks, including four major banks active in Sweden. The EBA's scenario specifies how various macroeconomic indicators (including gross domestic product (GDP), inflation, interest rates, unemployment, housing prices and equity prices) will develop in a so-called "baseline scenario" based on forecasts made by the European Central Bank (ECB) and in a stress scenario. In the stress test, Sweden is exposed to a very tough scenario: housing prices fall by almost 50 per cent, prices for commercial properties fall by over 40 per cent, GDP falls by just over 10 per cent and unemployment rises to over 12 per cent.

Somewhat simplified, there are two kinds of stress tests: top-down stress tests and bottom-up stress tests. The Riksbank uses a top-down stress test, meaning that all calculations are made by the Riksbank. Conversely, a bottom-up stress test implies that the banks make the calculations themselves, often under the oversight of a supervisory authority.[7]

There are advantages and disadvantages to both approaches. For example, a top-down stress test gives better possibilities for estimating systemic risks than does a bottom-up stress test. The reason for this is that the authority making the calculations can take account of the financial system as a whole. It is difficult to take account of systemic risks in bottom-up stress tests, as each bank makes its own calculations without considering the results of other banks. It may also be easier to compare results between banks in a top-down stress test as calculations are made in the same way for all banks included in the stress test. The Swedish banking system is concentrated to a small number of actors, making it interesting from a systemic risk perspective. This is why the Riksbank's stress tests are based on a top-down method which assesses the resilience of the entire Swedish banking system from a macrofinancial perspective and includes mechanisms that capture second-round effects

[5] In this staff memo, house prices and housing prices are used as synonyms.
[6] See, for instance, ECB 2010, EBA 2017, and Bank of England 2016.
[7] See Basel Committee on Banking Supervision 2017b for definitions and a comparison of top-down and bottom-up stress tests.

between banks. A top-down stress test also has advantages over a bottom-up stress test in the event of a financial crisis. This is because, in such a situation, a bank may have an incentive to underestimate its own risks, which could lead to market participants having low confidence in the results of a bottom-up-test.[8]

There are also disadvantages with a top-down stress test. For example, it is difficult to include some bank-specific aspects in a top-down stress test as these are primarily designed to assess the resilience of the system as a whole. The banks often have access to more detailed data than one usually has when carrying out a top-down stress test. It is therefore easier for them to include more detailed information in their bottom-up stress tests. This can contribute towards a bottom-up stress test taking greater account of the risks the banks are exposed to in various sectors than a top-down stress test can.

The Riksbank's methods for stress tests

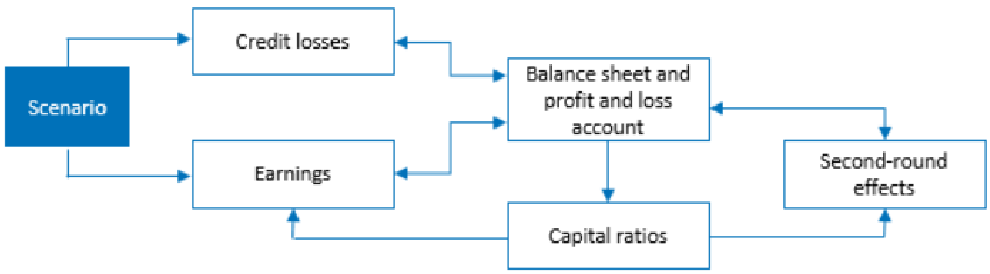
The Riksbank's stress test focuses, like other stress tests, on how the banks' capital ratios will develop in a stressed scenario. The most common way of reporting the banks' resilience is the change in the capital measures common equity tier 1 (CET1) capital ratio and leverage ratio. The Riksbank's stress test is designed to enable results to be calculated both for individual banks and for the system as a whole. In both cases, second-round effects are included.

The Riksbank stress tests the banks' capital using different models that estimate how different components in the banks' profit and loss accounts and balance sheets would be affected by different financial and macroeconomic factors. The current models have been developed in recent years and a central part of this development has been investigating how other authorities work with stress tests. The Riksbank has therefore compared its methods with the methods used by the Bank of England, Deutsche Bundesbank, De Nederlandsche Bank, the European Banking Authority, the European Central Bank, the Federal Reserve and Norges Bank. The aim of the comparison has been to create a starting point for the Riksbank's own further development of the methods. This comparison is summarised in Appendix 1.

The development work has resulted in new models to estimate the banks' credit losses, earnings and second-round effects in a stress scenario. In the section below, we briefly describe the results of the development work in these areas. Appendices 2-4 present detailed descriptions of the different models.

Illustration 1 gives a schematic overview of how the different parts of the stress test method relate to each other, and is followed by a descriptions of the mechanisms.

Illustration 1: Schematic illustration of the stress test's different parts



- The stress test starts with a macroeconomic scenario involving, for example, falling asset values, lower GDP and increased unemployment. The scenario plays out over several years, enabling the interaction of different models over time.

[8] Financial Stability Institute 2018.

- Usually, the macroeconomic development affects earnings in the banks negatively and leads to increasing credit loss levels.
- The credit losses and the reduced earnings, in turn, lead to the balance sheet and profit and loss account being impacted.
- Losses are absorbed by the capital in the bank, implying that the capital ratios fall.
- Lower capital ratios and reduced lending volumes affect earnings negatively. Deteriorating earnings will in turn limit the bank's ability to build up capital.
- As the banks are interconnected, the problems arising in the affected banks (reduced capital ratios) will spread to the entire financial system via second-round effects. In turn, the second-round effects affect the balance sheets, profit and loss accounts and capital in the banks.
- The results are expressed as the change in capital ratios during the time period which the stress test plays out.

The level of credit losses is an important part of stress tests

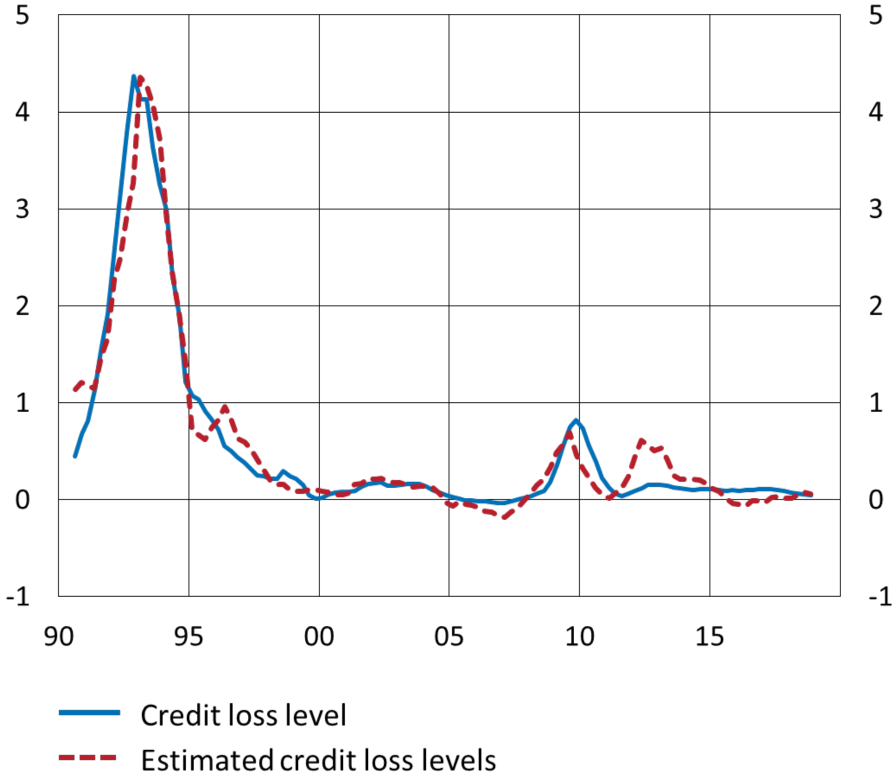
To estimate credit losses, the Riksbank uses a model in which credit loss levels (credit losses as a proportion of lending to the public) are estimated as a function of the development of:

- house prices;
- unemployment;
- government bond yields;
- the difference between treasury bill rates and the borrowing rates for companies;
- the general public's total debt as a proportion of GDP; and
- the proportion of lending to non-financial corporations.

Unemployment, interest rates and indebtedness capture demand in the economy and sensitivity to interest rates among households and companies. The change in house prices is included in the credit loss model as a non-linear function. This means that house prices and credit losses have a low correlation in normal times, but that heavily falling house prices can cause major credit losses.[9] As credit losses typically arise through lending to commercial actors, lending to non-financial corporations (as a percentage of the banks' lending to the general public) is also included. In addition to a correlation with credit losses in themselves, this variable captures how the banks' balance sheets now have a larger share of lending to the household sector than in the 1990s. The model is described in detail in Appendix 2.

[9] See Appendix A2 for a simple theoretical model (Vasicek 1987) that describes how house prices (which represents the value of collateral on the banks' lending) affect credit losses.

Figure 1. Credit losses for major Swedish banks
Percentage of lending to the public



Note. The graph shows aggregated credit losses from Handelsbanken, Nordea, SEB and Swedbank as well as the banks and credit institutions that historically have constituted these banks.
Sources: Bank reports and the Riksbank

The historical series in Figure 1 shows that major Swedish banks have normally had very low credit losses in recent decades. The figure also shows that credit losses increased heavily in the crisis of the 1990s, but also significantly in the global financial crisis of 2007–2010. Historically, there has been a non-linear relationship between the level of credit losses and the development of the economy, which is to say that the relationship between the credit loss level and various macroeconomic variables changes in crisis periods. This means that it is difficult to estimate the credit losses in a way that captures the relationship between the credit loss level and changes in, for example, unemployment and housing prices, both under normal economic circumstances and in crisis periods.

The Riksbank's method for estimating the credit loss level has therefore been developed to take account of this non-linear relationship. Consequently, the model takes into account that credit loss levels in normal periods are almost non-existent but are significantly higher in crisis periods. The red dashed line in Figure 1 shows the estimated credit losses according to the Riksbank's model. The estimated credit loss level clearly follows the historical actual credit losses in both normal periods and in periods of financial crises. The model thereby makes it possible that credit losses estimated in a hypothetical scenario also take account of the non-linearity in the relationship between credit losses and the macro scenario used in a specific stress test.

In addition to taking into account the non-linearity in the modelling of credit losses, there are a number of choices that will affect the credit losses the model generates and thereby also the outcome of a stress test. One example is the choice of which credit loss data is used in the credit loss model. The Riksbank's stress test is based on a credit loss model that estimates credit losses on the basis of a series of historical losses that includes the crisis of the 1990s. This was a period in which the banks made significant credit losses and the Swedish economy had major and protracted problems. At the same time, Swedish banks' credit losses have been very low over the last 20 years.

There are advantages and disadvantages in using series with long histories. It could, for instance, be a disadvantage to include the crisis of the 1990s, as the economic circumstances were different then. A credit loss model based on a shorter history could, however, underestimate credit losses that might arise in a future crisis. With a short history there is consequently a risk that the model will not fully generate an outcome that is representative for a severe crisis.[10,11]

Another choice that affects the credit losses that come out of a credit loss model in a stressed scenario is the model specification. Based on a credit loss series and a set of macro variables it is possible to specify several different models. The credit losses that arise from the different model specifications can vary substantially. By examining various specifications, in addition to those in the selected model, it is possible to gain a picture of how sensitive the credit losses are with respect to the different model specifications. The way that house prices are included in the model through a non-linear function means that they can have a large impact on the result of the stress test.

Earnings are important as a protection against credit losses

A bank's earnings must both cover the bank's normal operating costs and act as a buffer against credit losses. They can also be used to build up capital during, before and after a financial crisis. A bank with high earnings therefore finds it easier to cope with a period of high credit losses than a bank with low earnings.

The two largest sources of the banks' earnings are net interest income and net fee and commission income, which together account for over 85 per cent of the banks' total earnings[12]. The Riksbank's stress test uses two models for the banks' earnings: one for net interest income and one for net fee and commission income. In these two models, the development of net interest income and net commission income depends on various macroeconomic and bank-specific variables that are specified in a certain scenario. Both models include a variable that reflects the banks' capital ratios. In the model for net interest income, a deteriorated capital ratio means that bank's funding costs increase, as investors will presumably deem it more risky to lend to the bank. But net commission income can also be negatively impacted by the deterioration of a bank's capital ratio. In addition to this, lower stock market returns in the scenario also lead to the banks' net commission income falling. This is partly driven by presumably less business opportunities and decreasing brokerage incomes in an economic downturn.

Other operating incomes and costs are assumed to be constant in the stress scenario. This means, for example, that staff and premises costs are assumed to be unchanged. In combination with model estimates for net interest income, net commission income and credit losses, the banks' net result for the period is calculated, after which the balance sheet for the period can be calculated.

A detailed description of the earnings models can be found in Appendix 3.

Second-round effects can exacerbate stress

The major banks in Sweden are closely interconnected by significant exposures to each other through both their trading operations and their bilateral non-secured loans. In addition, the major banks have large holdings of each other's outstanding volumes of covered bonds.

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[10]See Andersen and Winje 2017, who illustrate the importance of having a sufficiently long history of credit losses from non-financial corporations for Norwegian banks. Historical loss data indicate higher average corporate risk weights than the current level in the Norwegian banking sector.

[11] Swedish banks' credit losses during the 1990s crisis are well in line with the rules of thumb for capital stress tests recently advocated by the IMF (Hardy and Schmieder 2013).

[12] Described simply, net interest income is the difference between a bank's interest revenue and its interest expenditure, while net fee and commission income (sometimes referred to *net commission income* only) is the difference between a bank's revenue from various fees paid by the bank's customers (for example card fees and brokerages) and fees paid by the bank for various services.

Apart from this, the banks are exposed to similar risks, for example through lending with Swedish properties as collateral, and they obtain funding largely on the same markets. All in all, this means that a problem arising in one bank can rapidly spread to another bank, which reinforces the shocks arising in the financial system.[13] Major Swedish banks also have significant operations outside Sweden, which means that economic shocks in other countries could spread to Sweden.

The Riksbank's method for stress tests contains two mechanisms that take account of such second-round effects. One of them captures the possibility that the direct exposures between the major Swedish banks may give rise to credit losses in the event their counterparties fail. The other captures the possibility that a bank in crisis may need to sell various operations or assets to ensure that the bank remains viable. When several banks encounter problems at the same time and carry out sales of assets, the market price for these assets is also affected, which means that a bank may face losses and reduced earnings even if the bank itself did not have any problems to start with. This is what is known as a "fire sale channel". Second-round effects in turn impact the banks' profits, balance sheets and capital.

A more detailed description of the models for second-round effects can be found in Appendix 4.

Stress affects capital

The level of the banks' capital is of great importance for the assessment of their resilience to financial risks and threats. The Riksbank's method for stress tests focuses on two different capital measures: common equity tier 1 (CET1) capital ratio and leverage ratio.

CET1 ratio and leverage ratio

$$\text{CET1 ratio} = \frac{\text{CET1 capital}}{\text{risk weighted assets}}$$

$$\text{Leverage ratio} = \frac{\text{T1 capital}}{\text{total exposures}}$$

In both equations the numerator is a measure of capital: CET1 capital for the CET1 capital ratio and Tier1 capital (T1) for the leverage ratio.[14] In the stress test, both capital measures decrease if the banks suffer credit losses.[15] A bank's T1 capital consists of CET1 capital plus 'Additional Tier 1 capital' (AT1).[16] The part called AT1 capital consists of debt instruments with long maturities and usually only makes up a small part of the bank's T1 capital. When capital falls below a certain level, the debt instruments forming AT1 capital are converted to CET1 capital.[17] The conversion thereby has a positive effect on the banks' CET1 capital, which increases the CET1 capital ratio. The conversion does not, however, affect the leverage ratio.

The denominator consists of risk-weighted assets for the CET1 capital ratio and total exposures for the leverage ratio, respectively. In the Riksbank's stress test, both risk-weighted assets and total exposures decrease as the banks make losses in the scenario.[18] The deteriorated economic conditions in the stressed scenario also mean that parts of the banks' lending is deemed to be higher risk, with the consequence that the risk weights for this

[13] See the article Interconnectedness in the financial system. *Financial Stability Report* 2018:1 Sveriges Riksbank.
[14] According to standards from BIS, Basel Committee on Banking Supervision (2017a).
[15] In the Riksbank's method for stress tests, it is not possible for the banks to raise their capital by rights issuing, meaning that the stress test is policy neutral.
[16] This means that T1 = CET1 + AT1.
[17] AT1 are debt instruments where the holder of the bonds receives a yield paid by the banks, just like normal debt instruments (e.g. covered bonds). What distinguishes the AT1 from a normal debt instrument is that the contract between the bank and the holder specifies a threshold level for the banks' CET1 capital ratio, below which the AT1 automatically converts into capital. The conversion means that the bondholder becomes a shareholder. The yields on the AT1 instruments are significantly higher than those on other bank bonds to compensate for the higher risk for the holder.
[18] It is also possible to assume that the assets grow during a scenario by new lending.

lending increase (so-called risk migration). All else equal, this means that the risk-weighted assets increase, which results in the CET1 ratio decreasing. As the leverage ratio is not calculated using risk-weighted assets, it is not affected by the risk in a bank's lending increasing (risk migration).

When the authorities carry out stress tests, they usually assume that no economic policy measures will be adopted in the stress scenario and that the banks do not implement any management actions. This tests the banks' ability to manage a financial crisis without any support measures. In a real crisis, authorities could implement various measures to increase demand in the economy and the banks could carry out issues rights to increase their capital, for example.

Alternatives to the Riksbank's methods are under development

Models for stress tests are a priority area both among researchers and among banks and authorities.[19] The Riksbank is following this work and will continue to develop its methods and models going forward. There are alternatives to the method we have described in this staff memo. One complement to the Riksbank's methods for stress tests is to base the calculations on market data to take into account market participants' expectations of, for instance, a bank's future earnings and credit losses. The market value of the shares in comparison with the price to book (P/B) and the Expected Default Frequency (EDF) are examples of such measures. It is also possible to calculate market-based measures of solvency on the basis of equity prices and then apply a stress scenario to the calculations.[20]

Another development area that the Riksbank is focusing on is detailed data such as microdata (which is to say data on individual loans) or portfolio data (for example, data per sector or type of loan) to estimate credit losses. This is carried out by modelling the probability of default (PD) of a borrower and loss given default (LGD). The advantage of such a model is that is captures to a greater degree how the banks' exposures change over time. One example is lending to commercial property companies in Sweden, which formed a significant part of total losses during the crisis of the 1990s. The risk in this type of exposure may have decreased in significance since the 1990s if the banks have learned the lessons of the crisis and improved their methods for risk assessment. In addition, the borrowers' ability to repay loans may have changed. The credit loss model that the Riksbank now uses does not capture changes in the banks' credit assessments. The main reason that the Riksbank does not currently use micro data or portfolio data is that the availability of long time series is inadequate. This short history of available data risks underestimating credit losses in a crisis.

The Riksbank also has access to some supervisory data (COREP and FINREP), which provides possibilities for a new type of analysis and further development of the methods. One component that could be modelled better with the help of these data sources is risk weights and risk exposure amounts. The risk weights are calculated using a non-linear function of PD and LGD, among other things. Small changes in PD and LGD can thus result in relatively large changes to a bank's CET1-ratio.

There is also further development potential for the assessment of second-round effects. The two new modules for second-round effects still lack a mechanism to capture how stress in the financial system affects the real economy (for example housing prices, investment, consumption and GDP) and how this, in turn, exacerbates stress in the banks. For example, banks can cope with periods of stress by increasing their interest rate margins and reducing lending. However, this would have a negative effect on the real economy that would then rebound on the banks.[21]

Different scenarios can also be used as a way of further developing the methods for stress tests. Many other central banks use several different scenarios to capture different risks. One

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[19] See Anderson et al. 2018.
[20] See, for example, Sarin and Summers (forthcoming).
[21] See Andersen et al. 2019 for a stress test where the banks' behaviour affects macroeconomic variables.

particular scenario can also be worked out to describe specific risks in the financial system, for example falling prices for commercial properties. One further method is to evaluate different possible scenarios given a certain probability for such a scenario occurring.[22]

Finally, the interaction between the banks' capital strength and liquidity is an area that could be further developed in the Riksbank's methods for stress tests. This is because the banks do not just expose themselves to credit risks, but also to liquidity risks by obtaining funding with debt instruments and deposits with shorter maturities. A bank with solvency problems often faces difficulty obtaining funding on the market, as investors can assess the bank to be less resilient. Solvency problems can thus create liquidity problems, and vice versa. This is a central area, as the Riksbank is the authority that has the facility to give liquidity support to individual institutions in the form of emergency liquidity assistance (ELA).

The Riksbank has the task of promoting a safe and efficient payment system. Carrying out this task demands stability in the financial system and a strong banking sector. Stress tests are an important element of the Riksbank's analysis of the financial system's resilience to financial risks and threats. At the same time, there is uncertainty over this type of analysis, as it aims to illustrate the risks in scenarios that have not occurred. At the same time, banks' capacity to manage an economic crisis can be evaluated in different ways. In this way, different types of stress test complement one another and it is therefore important to use different methods when stress testing the banks.

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Appendix A1 Benchmark against other authorities

The benchmark exercise against other authorities aims to find gaps between the Riksbank's stress testing exercises and the best practice among other authorities, as well as feasible ways to narrow these gaps. The benchmark exercise consists of two parts. The first part focuses on the comparison between the Riksbank's old framework[23] and that of other authorities in order to identify the priority areas for improvement. The second part focuses on the modelling method comparison of the identified improvement areas among the authorities in the benchmark group that use a top-down approach.

Based on the benchmark exercise and the characteristics of the Swedish banking system, the following improvements have been made to the old Riksbank framework: the credit loss estimation model has been improved; items on the income statement are modelled as a function of the scenario; fire sales and contagion are included in the framework.

Benchmarking stress test frameworks

The first step of the benchmark exercise is to compare the Riksbank's old stress test framework with that of other authorities around the world, with the purpose of identifying the areas that should be given priority for improvement. This part of the benchmark exercise focuses on the framework rather than the modelling details, and on stress tests with a systemic perspective. The institutions focused on in the framework benchmark are those in the forefront of the area with similar objectives as the Riksbank: Bank of England (BoE), Deutsche Bundesbank (DB), De Nederlandsche Bank (DNB), the European Banking Authority (EBA), the European Central Bank (ECB), the Federal Reserve (FED), and Norges Bank (NB).

In order to provide some structure to the benchmark exercise, different features of a stress testing framework are sorted into three different areas that are especially important with regard to the Riksbank's framework and the characteristics of the Swedish banking system. The areas are: credit risk; income statement and market risk; and second round effects plus feedback loops. Table 1 shows a summary of the results of the stress test framework benchmark exercise. The rest of this section describes the benchmark exercise for each of the three areas and corresponding improvements that have been implemented by Riksbank.

[23] The old framework refers to the methods used in the Riksbank's previous stress tests. See the Riksbank's Financial Stability Report 2015:2.

Table 1. Summary of stress test framework benchmark exercise

	BoE	DB	DNB	EBA	ECB	FED	NB	RB old	RB new
Credit risk									
Function of scenario	X	X	X	X	X	X	X	X	X
By sector and region	X	X	X	X	X	X	X	X	
Link to micro data			X		X				
Income statement and market risk									
Hair-cut								X	
Function of scenario	X	X	X	X	X	X	X		X
Link to micro data			X						
Net interest income*	X	X		X	X				X
Interest income linked to scenario		X	X			X	X		
Funding cost linked to scenario		X	X			X	X		
Trading book linked to scenario	X	X	X	X	X	X	X		
Account for "strategic" dividend policy	X			X			X		X
2nd round effects & feedback loops									
Fire sales					X				X
Contagion		X			X				X
Macro-feedback					X		X		

Note: Column "RB old" shows the methodology for the Riksbank before improvements. Column "RB new" shows the methodology for the Riksbank after the improvements. "Link to micro data" refers to using micro data for modelling by the benchmark authorities, not by the banks themselves in the bottom-up stress test.
*The Riksbank also models net fee and commission income in the stress test.

Credit risk

Credit risk modelling plays a crucial role in the overall stress testing model suite and is typically the most developed part in the stress testing framework for all benchmark authorities. Credit risk can be modelled in many ways. It can, for example, be done very granularly by using micro data to model the probability of default (PD) and loss given default (LGD) for different sectors. It can also be done by modelling a (group of) banks' credit losses directly as a function of the scenario. The advantage with the former is that it is able to incorporate more information on the lender and its borrowers, but the data requirements are substantial. As shown in Table 1, all benchmark authorities model credit risk as a function of the scenario, and by sector and region. DNB and ECB use models based on micro data (e.g. household-level data) to assess credit losses.

Improvements to the Riksbank's framework

Under the old framework, a linear relationship was assumed between economic development and credit losses. In a linear model, credit losses typically increase when asset values fall and GDP declines. But a linear model (by definition) cannot capture the feature that losses are likely to be small in normal times or even in a minor recession, but can be very large for major recessions, such as the 1990s crisis in Sweden. The new credit risk model includes a non-linear relationship between macroeconomic variables and credit losses. Nonlinearities can capture a steep increase in credit losses when a deep recession hits the economy. The new credit risk model focuses on the aggregate credit losses in the Swedish banking system as the available time series for the aggregate credit losses is long enough to cover the 1990s crisis in Sweden. More granular data including detailed information on PD and LGD for individual banks' portfolios is partially available but with much shorter time series. As Swedish banks' credit losses have been very low since the 1990s crisis, a credit loss model based on data without including the 1990s crisis period may underestimate credit losses in an adverse scenario.

Income statement and market risk

All authorities in the benchmark exercise model at least parts of the income statement as a function of the scenario. Some authorities model interest income and interest expenses separately, while others model net interest income directly. Some authorities take the modelling a step further by using different models for interest income from different sectors, and different models for the cost of different funding sources. In the case of DNB, some of these models are based on micro data. The benchmark authorities also have models to assess losses in the trading book. This is usually done by modelling gains and losses on financial items separately. There are only three authorities (BoE, EBA, NB) in the benchmark exercise that include assumptions on how dividends could be disbursed under different scenarios.

Improvements to the Riksbank's framework

In the Riksbank's old framework, a 20 per cent hair-cut on consensus forecasts of banks' earnings was applied, which lacks the link to the scenarios. In the Riksbank's new framework, the net interest margin and net fee and commission margin are modelled as a function of macroeconomic variables, which is a significant improvement. Though trading income hasn't been modelled specifically yet under the new framework, it is similar to fee and commission income, and will be considered for future development of the stress test framework.

Second-round effects/feedback loops

Feedback loops and second-round effects are features which many authorities are currently working on. These features can work in many different ways, but the general idea is that banks will change their behaviour when faced with credit losses and deteriorating capital ratios. A bank could for instance raise interest rates (or reduce deposit rates), reduce credit supply or sell loans and other assets. Such behaviour in turn can have a negative effect on other banks, financial markets, customers, and eventually the macro economy. The initial macroeconomic shock can therefore be amplified, and spill over to other banks. Modelling of the second-round effects can be categorized as follows: (i) contagion impacts within the banking sector; (ii) fire sales from deleveraging distressed institutions; and (iii) feedback effects on macroeconomic variables. Among the benchmark authorities, only DB and ECB have modelled interbank contagion specifically. ECB and NB have also included feedback from the stress experienced by banks to the scenario. Many authorities such as ECB, BoE and NB have started working on modelling the fire-sale channel. However, only ECB seems to have implemented the fire-sale mechanism in the stress testing framework.

Improvements to the Riksbank's framework

The Riksbank's old stress test framework only included losses stemming from the failure of the bank's largest counterpart. A significant improvement to the Riksbank's framework is that two modules which quantify the effects of an interlinked banking system—contagion and fire sales—have been implemented in the new stress test framework. The contagion module is developed based on the method presented in Espinosa-Vega and Solé (2011). The fire sale module is developed from the framework by Cont and Schaanning (2017). Finally, the models for the income statement include a feedback effect from bank capital to earnings, which amplifies adverse shocks.

Benchmarking modelling methods

After benchmarking the Riksbank's old stress test framework against that of other authorities and identifying the high-priority areas for improvement, a further step has been taken to benchmark how other authorities have modelled those areas. This section compares the modelling methods for those areas by four benchmark authorities—DB, DNB, ECB and

NB—as they employ a top-down approach in their macroprudential stress tests and have more detailed documentation on their modelling methods.[24]

Income statement

Components modelled

All benchmark authorities model interest income and interest expense (or net interest income) at the bank level as a function of the scenario. For other income components in the income statement, net fee and commission income and trading income, both normalized by the total assets, are explicitly modelled by some authorities.

Function of scenario

When modelling income components, all authorities in the benchmark exercise link the outcome variables to the macroeconomic variables in the scenarios, typically using a linear panel regression model. However, the macroeconomic variables that they link to the outcome variables vary across authorities. The ECB even uses a variable selection procedure—the least angle regression (LARS) algorithm— to select which macro variables should be included in the panel regression.

Modelling methods

Most authorities employ a (dynamic) panel regression approach to model the net interest income or the breakdown of interest income and interest expense.[25] This approach uses a linear regression model to link net interest income or its breakdown to the macroeconomic variables under the scenario (and the lag of the dependent variable if it is a dynamic panel regression approach).

Besides the dynamic panel regression approach, the ECB also uses a sophisticated approach which models interest rate spreads by asset and liability segment conditional on a given macroeconomic scenario, and then projects the net interest margin in conjunction with loan stocks. To mitigate modelling uncertainty, Autoregressive Distributed Lag (ADL) equations in combination with the Bayesian model averaging (BMA) technique are used.

In DNB's model for the projections of interest income and interest expense, there is a special feature consisting of a funding shock tool that captures the effects from banks' strategic or pricing considerations[26] in addition to those from interest rate developments in financial markets. The model exploits granular information at the portfolio level, and projects the interest income or expenses by adjusting the effective interest rate of the portfolio according to a prescribed scenario path of the portfolio interest rate series, in line with imposed assumptions on funding costs and their consequences for price-setting behaviour.

Among other income statement components, only fee and commission income and trading income (both normalized by the total assets) are explicitly modelled by some of the benchmark authorities, using panel regressions and quantile regressions, respectively.

Credit risk

Components modelled

Most benchmark authorities, including DB, DNB and the ECB, model both PD and LGD with stress factors that link to the scenario, for parts of or the entire loan book. NB employs a

[24] Bank of England (BoE), the Federal Reserve (FED) and the International Monetary Fund (IMF) also have comprehensive stress-testing frameworks. However, they are not suitable candidates for benchmarking modelling methods for our identified new features. FED and BoE employ a bottom-up or a hybrid approach instead of a top-down approach for their stress tests. IMF conducts the stress tests under their Financial Sector Assessment Programs (FSAPs) and the methods can vary substantially across FSAPs for different countries. Therefore, it is very challenging to identify a general methodological framework that is marked as "IMF approach". The European Banking Authority (EBA) conducts an EU-wide stress test exercise which covers the four major Swedish banks; however, the EBA stress test also uses a bottom-up approach and is not designed per se to identify systemic risks. Due to the reasons described above, BoE, FED, IMF and EBA are not included in the benchmark exercise on modelling methods.

[25] The net interest income, or the breakdown of interest income and interest expense are all normalized by the total assets.

[26] For example, banks may set lending and deposit interest rates according to their long- and short-term strategy. They may decide to raise deposit rates above market rates to attract liquidity, or to keep loan rates stable to gain market shares even though market rates have risen.

different approach compared with other authorities. They use two loss functions, one for projecting the loan losses related to the flow of new problem loans,[27] the other for projecting loan losses arising from the stock of problem loans. The key components in the loss functions are the problem loan share and the loss rate on problem loans, which share some similarities with the methodology applied by banks using internal ratings-based (IRB) approach to estimate PD and LGD.

Link to scenario

All authorities in the benchmark exercise link the modelling components (credit losses as a whole, or PD/LGD) to the scenario. However, the macroeconomic variables that are linked to the outcome variables vary across sectors and authorities.

Modelling methods

Most authorities model PD and LGD separately as a function of the scenario for different sectors. PD is the most focused component in credit risk modelling for all benchmark authorities. The ECB uses the BMA econometric technique to estimate the top-down parameter paths, similar as to how they model the front-book interest rates. The dependent variable is the logit level of the default rate; the control variables include the lags of the dependent variable and selected macro-variables. The estimation is executed individually by portfolio segment. The macro-financial factors that are actually included in the regression along with the sign restrictions are different for different asset and liability segments.

PDs in DB's credit risk model are based on initial average bank estimates for the last year in the data (2014 in this case as the document is written in 2015), plus a stress add-on which mirrors the cumulative change of the aggregate unemployment rate since the end of the last year in the data, albeit with a time lag of one year.[28] In order to take into account improved loan servicing over time, PDs are set to zero after seven years without a default.

DNB models the PDs under the stress scenario using a transition matrix approach. It starts with the PDs in the common reporting (COREP) data, which are PDs by asset class and by risk bucket and defined as being through-the-cycle (TTC). As the stress is supposed to occur at a specific point-in-time (PIT), the reported TTC-value of PD in COREP should be adjusted to a PIT-variant. The translation from the reported TTC PDs to the PIT PDs is achieved through an adjustment factor, which is determined for each portfolio and based on the most recent loss data in the market relative to the long-term average. Then, the PIT PD estimates are converted to stressed PD estimates using a stress factor. The stress factor is a function of macroeconomic variables.

Most of the benchmark authorities, including the ECB, DB and DNB, model LGD explicitly, but only for real-estate loans. For example, the ECB models LGD for housing-related loans as the sum of administrative costs and the multiple between the loss-given-liquidation and (1-recovery rate). LGD in DB's credit risk model for mortgage loans is estimated bank-by-bank for each region and each LTV bucket. It is directly related to the recovery rate in the case of default. DNB models LGD using a similar method for PD. For the LGDs for other segments, a fixed multiplier or expert judgement are usually applied by the benchmark authorities.

DB models PD and LGD only for mortgage loans, perhaps due to data limitation. However, they also link the total credit losses as a whole to the scenario using panel regression for large banks and sector regression for small banks. The econometric model used for the aggregate credit losses for large banks are quite similar to the one used for net interest income (or net interest expense). For small banks, sectoral regressions are used instead to take advantage of the data on the detailed breakdown of domestic loans from the DB's borrowers' statistics.[29]

NB models credit losses for both the stock and the flow of problem loans using two separate loan loss functions. The credit losses are estimated for each sector but not bank by bank. For the flow of problem loans, loan losses for each sector during each quarter are

[27] The term "problem loans" refers to the sum of non-performing loans and other loans with a high probability of default.

[28] The time lag of one year is based on the assumption that a borrower does not default at the exact instant of becoming unemployed but when dissaving all their assets.

[29] The domestic credit portfolios make up 98 per cent of the loan portfolios for small German banks on average.

modelled as the sum of the "change effect" and the "write-off effect". The change effect indicates losses attributable to the net change in problem loans, which is the multiple of the following three factors: net loans in the previous quarter; the change in the problem loan share; and the loss rate on problem loans. The write-off effect shows losses when existing problem loans from the previous quarter are written off and replaced by new problem loans, which is the multiple of the following four factors: net loans in the previous quarter; the problem loan share in the previous quarter; the percentage of the previous quarter's loans written-off (write-off rate); and the loss rate on problem loans. The problem loan share for the corporate and household sectors is modelled as part of the projection of the stress scenario. The write-off rate and the loss rate on problem loans are based on assumptions. The credit losses for the stock of problem loans are estimated by the multiple between the volume of problem loan stock and the loss ratio, where the loss ratio is a decreasing function of time and often set by judgement or calibrated to historical loss levels.

Modelling specific sectors using micro data

The ECB and DNB are pioneers among the benchmark authorities at using micro-level data of household balance sheets to estimate mortgage credit losses. The ECB's integrated dynamic household balance sheet model contains six core modules. DNB uses a micro-simulation of household balance sheets combining loan-level data of banks to calculate mortgage credit losses for estimating PDs for the mortgage lending portfolios.

Though the micro-data approach is becoming popular for modelling credit risk for stress testing purposes, it is mainly used for the household sector. As far as we know, there are as yet no benchmark authorities using or developing a micro-data modelling approach for the corporate sector.

Second-round effects/feedback loops

Interbank contagion

Interbank contagion means that banks experiencing a capital shortfall in the stress test would not be able to repay their interbank obligations, which could trigger a chain of second-round defaults of other banks in the system.

There are generally two approaches for modelling interbank contagion in the literature.[30] One is called "the cascade algorithm", or "round-by-round" algorithm. This approach starts with exogenous defaults of one or more banks, and banks that have exposure to those defaulted banks suffer credit losses and equity decrease. If credit losses due to the exposure to defaulted banks are substantial, it may trigger default of these banks as well and transmit the original shock. The process can continue until no new defaults occur. The other approach is "endogenous loss distribution" (see Eisenberg and Noe, 2001), which also starts with one or more exogenous defaults. This algorithm distributes the losses among the banks in the interbank market such that no new defaults occur. In contrast to the cascade algorithm, the amount of necessary write-downs is endogenously determined. Among the benchmark authorities, the ECB, DB and NB have modelled interbank contagion. DB applies the cascade algorithm, while the ECB uses the endogenous loss distribution approach. NB hasn't explicitly described how they model the contagion effect.

Fire sales

Fire sales are an important channel which captures the effect that distressed financial institutions need to liquidate part of their securities portfolio, which may adversely affect asset prices and further depress the banking system's solvency and liquidity. Currently, many authorities such as the ECB, BoE and NB have started working on modelling the fire-sales channel. However, only the ECB seems to have implemented the fire-sale mechanism in their stress testing framework.

[30] See more descriptions in Deutsche Bundesbank, 2015.

According to the description of the ECB's STAMP satellite model, the "fire-sales" mechanism is integrated as an indirect channel of the module for interbank contagion. In order to meet the interbank payment obligations, banks may need to shed some assets to cover the resultant liquidity shortfall. The fewer interbank assets they receive back, the higher the liquidation need. This may adversely affect the mark-to-market valuation of the assets and further depress banks' capacity to pay back their interbank creditors.

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Appendix A2 Credit risk

Credit risk is the risk that borrowers are not able to repay their loans. Credit risk is typically the main solvency risk for banks: the traditional business model of commercial banks is to borrow money from depositors and investors, and to lend money to firms and households. If the banks' borrowers cannot repay their debt to the bank, the bank will suffer a loss.

Banks manage credit risk in several ways. First, banks screen whether loan applicants have sufficiently large cash flows (income for households, earnings for firms) to fulfil their debt obligations, resulting in a risk classification. The riskiest borrowers are likely denied the requested loan. Second, banks charge higher interest rates to riskier borrowers, and thus price in the risk of defaults (the so-called risk premium). For a large bank with a diversified loan portfolio, the default of some customers will be compensated by the risk premium charged to the entire portfolio. Third, banks often require the pledging of collateral. Real estate is a prime example of collateral backing up loans to households (mortgages) and firms. The availability of collateral will dampen the loss for banks, as banks can claim and sell the collateral posted by defaulting borrowers. Fourth, banks provision for expected lending losses. For a large bank with a diversified portfolio, incurred or expected loss provisioning[31] tends to smooth losses and earnings over time.

Despite risk management practices, banks' credit risk is ultimately uninsurable. History shows that credit losses are small most of the time, but very large at other times (see Figure 1). The 1990s crisis in Sweden was characterized by large losses on loans, which led to defaults of several commercial banks and an extended period of financial instability.

An empirical model for credit losses

The Riksbank's stress test framework features an empirical model for credit losses. The model relates credit losses of the major banks to macroeconomic variables. For a given path of the macroeconomic variables specified in the scenario, the model provides an estimate of scenario credit losses.

The dependent variable in the model is the loan loss ratio, defined as the credit losses incurred during the last 4 quarters divided by loans to the public. The data comes from banks' quarterly reports. To construct long time series, the Riksbank has collected the same information for the predecessors of present-day banking groups.[32] Excluding the banks that failed (e.g. Gota Bank) during the 1990s crisis would lead to a severe underestimation of credit losses. The loan loss ratio series is compiled at a quarterly frequency starting in 1989:Q4 until today.[33]

While the data is available bank by bank, the model is estimated using aggregate data (that is, the banking system's credit losses divided by the banking system's loans to the public). One reason is that it is difficult to place the failed banks of the 1990s into present-day banking groups. For instance, the performing assets of Gota Bank were taken over by Nordbanken, which later became Nordea. Putting all of Gota Bank's credit losses under Nordea would result in much larger predicted losses for current Nordea relative to the other banks. Moreover, the Riksbank is mostly interested in testing the resistance of the banking sector as a whole, and an aggregate model seems better suited for this purpose.[34]

The independent variables include the unemployment rate, the growth rate of real house prices, interest rates on a government bond with five year remaining maturity and the spread

[31] Provisioning practices vary with accounting standards and across countries. For a discussion of the recently implemented IFRS-9 accounting standards which imply a shift from incurred loss to expected loss provisioning, see Frykström and Li (2018).

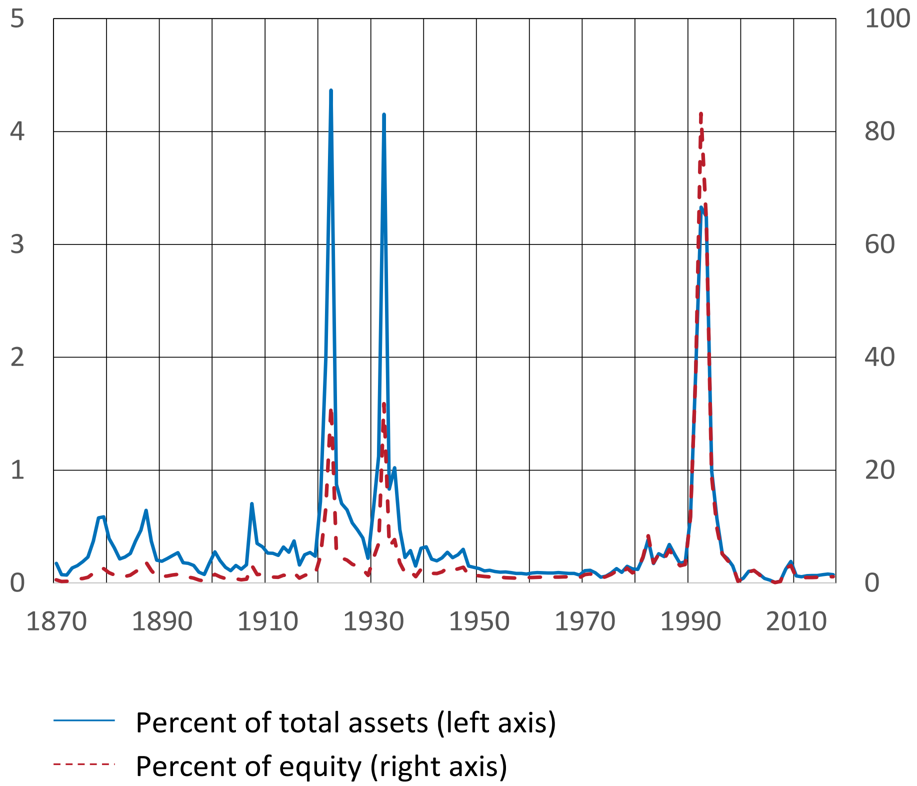
[32] Nordbanken, Gota Bank, Föreningssparbanken, Föreningsbanken and Sparbanken Sverige.

[33] The loan loss ratio uses banks' provisioning for incurred and expected losses, rather than actual write-offs. This is the correct variable to use given that the goal is to compute profits after loan loss provisioning.

[34] We have cross-checked the constructed loan loss series from banks quarterly reports to aggregate data from SCB spanning the period 1996-2017 in combination with historical data from Riksbank Statistical Yearbooks spanning the period 1984-1995. The aggregate loan loss ratios are nearly identical. The empirical model gives very similar parameter estimates when estimated with quarterly series from the Riksbank or annual series from SCB/Yearbooks.

between the corporate lending rate and a 6-month treasury bill. Finally, we include borrower leverage (as proxied with the credit to GDP ratio).

Figure 1. Historical credit losses for Swedish banks
Per cent



Source: Hortlund (2005) and Statistics Sweden.

Analogy with models of corporate bankruptcies

Predicting corporate defaults is the topic of many papers in corporate finance. Going back to Altman (1968), most models are estimated using balance sheet and/or market data on both surviving and defaulting corporations. The aim is to find the best predictors of defaults. The key findings are that various financial ratios from corporate balance sheets in combination with aggregate macroeconomic and financial variables are the best predictors of defaults.[35]

The financial ratios used to predict bankruptcies virtually always include measures of earnings, interest coverage and leverage (debt to assets). Earnings are a good proxy for the cash flow needed to avoid repayment issues. Higher interest payments and higher leverage are associated with a larger risk of default.

The empirical model of credit losses used in the Riksbank's stress test builds upon the corporate bankruptcy literature. Lacking firm-level data on all of the major banks' customers, we employ aggregate variables as opposed to firm-level balance sheet variables. Cash flow and earnings are naturally approximated by demand factors such as GDP and the rate of unemployment.[36] Interest coverage is approximated by the economy-wide interest rate level (we use the rate on government bonds with 5 years remaining maturity)[37] and the spread between the interest rate for corporate loans and the interest rate on a treasury bill. The aggregate equivalent to firms' leverage is the economy's leverage, computed as credit to GDP. Furthermore, we use house price growth to capture changes in the price of collateral.

[35] Relevant papers in the literature include Altman (1968, 1971), Shumway (2001), Duffie et al (2007), Bharath and Shumway (2008), Jacobson et al (2013) and Giordani et al (2014).
[36] The GDP growth rate and the unemployment rate are strongly correlated in the data. We include the unemployment rate instead of the growth rate in GDP based on the goodness of fit of the regression model. Including GDP and the unemployment rate yields positive and insignificant coefficient estimates for GDP and does not improve model fit.
[37] The 5-year rate has the best fit when testing against longer or shorter maturities.

An important feature of the empirical credit loss model is that the growth rate of real house prices enters non-linearly.[38] The motivation is that periods with (sharply) falling house prices are especially dangerous for financial stability: lower housing prices reduce the value of collateral pledged to banks, and in addition increase the likelihood that households with mortgages cut back on consumption. The nonlinearity imposed is a parsimonious way of capturing nonlinearities observed in the data, and yields a substantial improvement in the model fit.

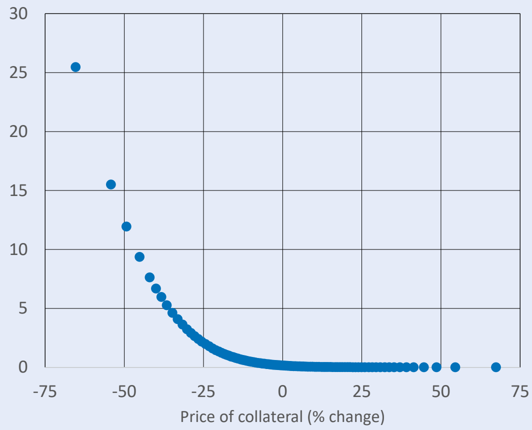
Nonlinearities follow naturally from credit risk models

In models for credit risk, corporate bankruptcy occurs when the value of the firm's assets (which evolve stochastically) is lower than the value of its outstanding liabilities. This is a non-linear event: for some (bad) realizations of asset values, firms default, whereas for most other (more benign) realizations, firms keep repaying their debt.

To illustrate this point, consider the classical Vasicek (1987) model, in which asset values evolve according to $A_{i,t} = \exp(\alpha_{i,t-1} + bz_t + \epsilon_{i,t})$. In words, asset values today are affected by past asset values, a common factor z and an idiosyncratic (i.i.d.) shock ϵ. The common factor can be interpreted as the price of collateral, such as real estate. Firms default when debt exceeds the asset value: $D_{i,t} > A_{i,t}$. The losses for the bank if firm i defaults equal $Loss_{i,t} = D_{i,t} - \tau A_{i,t}$, where τ denotes the recovery rate on assets.

Figure 2. Simulated credit losses from a simple credit risk model

Per cent of loans



Source: The Riksbank.

Note: the diagram illustrates the non-linear effect of changes in the value of collateral for portfolio credit losses. Data is simulated from the simple Vasicek (1987) model outlined in the text with parameters $D_{i,t} = 0.5, A_{i,0} = 0, b = 1, \epsilon_{i,t} \sim N(0, 0.25^2), \tau = 0.5$

Figure 2 plots the relationship between bank losses (as a share of loans) and the price of collateral using data simulated from the Vasicek (1987) model. For positive or even small negative price shocks, credit losses are negligible. However, losses increase dramatically when the shock becomes more and more negative. While the level of losses is mostly determined by the chosen parameters in this very simple simulation exercise (such as the variance of idiosyncratic shocks and the level of leverage), the main feature that losses increase sharply with falling collateral values survives regardless of the calibration.[39] In the stress test, we choose house prices as a proxy for the price of collateral. We note that commercial real estate prices and house prices correlate strongly over time, so choosing house prices as a proxy will not distort estimated loss levels related to, for instance, commercial real estate lending.

[38] To be precise, we include a dummy for negative real house price growth interacted with the level of real house price growth. Nominal house price growth rates are deflated using the CPIF. We use a 2-year trailing average for real house price growth in the regression. This specification is based on testing different lag lengths empirically, and captures the idea that short-lived house price declines are less likely to result in credit losses, whereas extended periods with falling house prices can result in losses.

[39] Duffie et al. (2009) discuss how the omission of common unobservable risk factors in portfolio loss models (such as the Vasicek model) can create severe downward biased estimates of default risk. Such common factors are an additional motivation for having non-linear models, as the risk of default suddenly increases for all loans exposed to the risk factor.

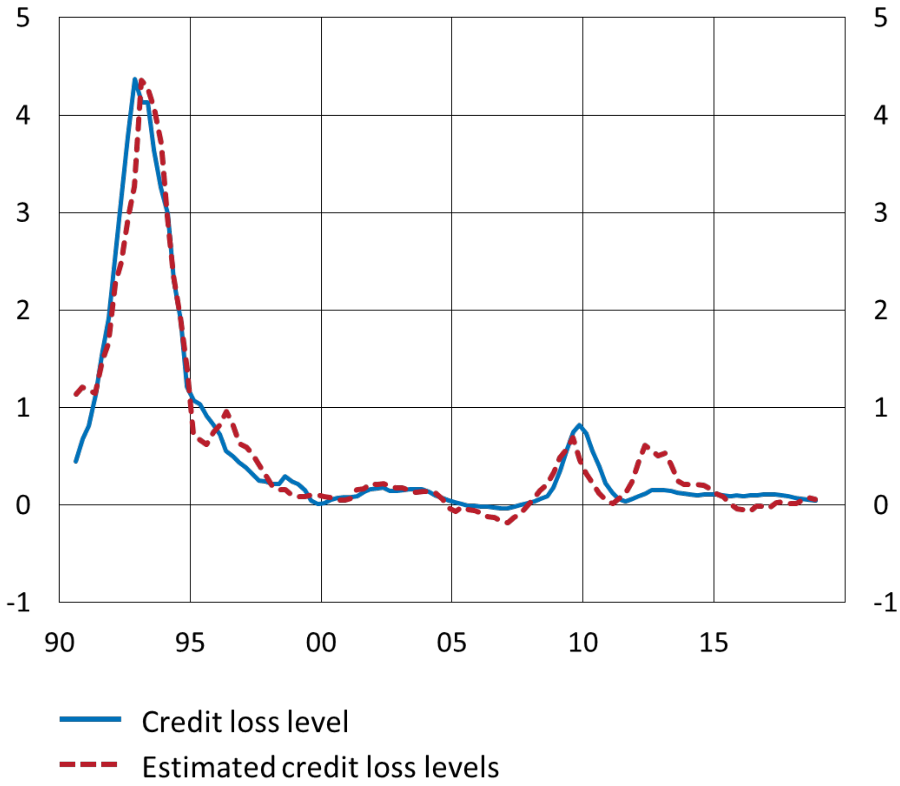
To capture bank balance sheets changing over time, we control for the share of loans granted to corporates (as opposed to households).[40] Corporates are more likely to default, causing credit losses to the banks. As Swedish banks, since the 1990s crisis, have become increasingly focused on lending to Swedish households (primarily mortgages), we capture an important driver of the reduction in credit losses observed in the data.[41]

We estimate the following model with ordinary least squares (OLS):

$$\frac{Credit\ losses}{Lending\ to\ the\ public} = \alpha + \boldsymbol{\beta X} + \varepsilon$$

Where X is a matrix with the change in the unemployment rate (4-quarter trailing average), the 5-year government bond rate (4-quarter trailing average), the difference between lending rates to non-financial corporations and the interest rate on a treasury bill with 6 months remaining maturity (4-quarter trailing average), the credit to GDP ratio, the change in real house prices (2-year trailing average) times an indicator that is equal to 1 if negative, and lending to non-financial corporations divided by lending to the public (1 quarter lag).

Figure 3. Credit loss ratios of the major Swedish banks
Per cent of loans to the public



Note. Aggregate for Handelsbanken, Nordea, SEB, and Swedbank as well as the banks and credit institutions that historically have constituted these banks.

Sources: Banks' quarterly reports and the Riksbank.

Figure 3 shows the aggregate loss ratio for the major Swedish banks, as well as the fit of the regression. The model is able to replicate both the large losses observed in the 1990s

[40] Financial market statistics from Statistics Sweden is used to obtain loans to Swedish non-financial firms and loans to Swedish non-MFIs. Since loans to housing cooperatives are classified as lending to non-financial firms, although such loans are ultimately serviced by households, we subtract loans to housing cooperatives from loans to non-financial firms. The share of loans to corporates is a ratio between loans to non-financial corporates (net of housing cooperatives) and loans to non-MFIs.

[41] The share of loans to corporates does not capture potential changes of the loan allocation within the class of corporate loans. There is no good historical data on, for instance, sectoral balance sheets. However, a rebalancing of loan portfolios towards customer types that haven't defaulted in the past should not be interpreted as a sign of low loan losses in the future, just because sectoral risks might not have materialized in the past.

crisis, as well as the long period of low loss levels thereafter. The estimated model shows that losses increase when interest rates, corporate spreads and unemployment increase, and when the economy is more levered. Negative house price growth has the strongest impact on credit losses. A higher share of loans towards corporates also contributes to higher loss ratios.

Just as in all empirical modelling, the choice of model specification will affect both in-sample fit and scenario losses. By trying out different specifications, the sensitivity of the scenario losses with respect to model specification can be assessed. It turns out that the non-linear effect of house prices plays a central role in modelling the historical credit loss series. Other macroeconomic variable also have some effects on losses, but their quantitative impact is smaller. As such, leaving out house prices, or not including the non-linear effect from house prices, worsens the fit and (depending on the house price scenario) is likely to result in lower scenario credit losses. For a given specification, tougher scenarios will result in larger credit losses. At the same time, for a given scenario, different model specifications can give either lower or higher credit losses in that specific scenario. This uncertainty is important to keep in mind when reviewing the stress test results. The preferred specification strikes a balance between having a simple model with a few macroeconomic variables, capturing the historical non-linear relation between house prices and credit losses, and having a good fit with explanatory variables that are both economically relevant and important from a financial stability perspective.

Scenario credit losses

The empirical model outlined above is used to estimate losses in the stress test scenario. Loss ratios in the scenario are equal to the estimated regression parameters multiplied by scenario values for the macro variables. As with any statistical model, the estimated parameters have a degree of uncertainty, reflected in the standard errors of the estimates. This means that estimated loss ratios could both be higher and lower. It turns out that the parameters are estimated rather precisely, and that standard errors around the forecast are rather small.

The scenario specifies paths of house prices, the unemployment rate, the government bond yield and the lending rate for non-financial corporates. Leverage is kept fixed at its most recent value throughout the scenario.[42] However, the scenario cannot tell us what happens to the share of loans granted to corporates, as it will depend on credit losses. Keeping the corporate loan share fixed is likely to produce upward-biased estimates of credit losses as loans to corporates are more likely to cause losses. In the adverse scenarios, the share of loans granted to corporates declines over time.

Scenario path for the share of loans granted to corporates

The share of loans to corporates in the adverse scenario is determined as follows. We use banks' 2018-Q4 data (from annual reports) on the share of loans to corporates as the starting point. The adverse scenarios subsequently generate credit losses, which will stem from corporates to the largest extent. The assumption maintained is that the share of credit losses from corporate lending is proportional to the share of risk exposure amounts (REAs) for corporates. This REA share ranges between 69 and 84 per cent, indicating that corporate lending is substantially riskier than retail (household) lending. For each scenario period, we update lending to the corporate sector using the past value of corporate lending minus (preliminary) estimated losses from corporate lending (i.e. the corporate REA share times estimated credit losses in SEK). Similarly, we update lending to households using the past value of lending to households and the preliminary estimate of losses to the household sector (i.e. one minus the corporate REA share times estimated credit losses in SEK). Lastly, we use the updated corporate share to predict loss ratios.

[42] In a scenario where GDP falls, leverage would typically increase (as credit is fixed in the short term). This increased leverage (in combination with the positive marginal impact estimated in the regression) subsequently increases estimated credit losses. By keeping leverage fixed instead, we make sure not to amplify losses in the scenario.

To translate the estimated loss ratios (credit losses as a percentage of loans to the public) to credit losses in SEK, we use the fact that losses in scenario year *t* are equal to the credit loss ratio estimated in the model times loans to the public, while loans to the public in year *t* are equal to loans to the public in year *t-1* minus credit losses. We iteratively update loans to the public and credit losses for each scenario year.

A final issue that needs to be addressed is the international dimension of bank activities. The credit loss model is estimated using Swedish macroeconomic data, whereas credit losses are at the group level, and could therefore come from different countries. Since credit loss data by country of counterparty is not available historically, we cannot test how sensitive the model is to more granular (portfolio) data. However, we note that the model gives correlations between banks' credit losses and macroeconomic variables. Hence, we implicitly assume that the correlation between credit losses and, say, changes in the rate of unemployment, is similar between countries, and that using the Swedish correlation does not give biased estimates for the portfolios in the other Nordic or Baltic countries plus the United Kingdom and Germany.

For scenario losses, we do take into account the different exposures in different countries. The countries differ in terms of the path of macroeconomic variables in the scenario, such as that from the EBA. Part of this stems from differences in the baseline (for instance, the Baltic countries and Denmark were significantly more affected by the financial crisis than Norway and Sweden) whereas scenarios can also specify different degrees of severity for different countries. In Sweden and Norway, where house prices and leverage have risen sharply in the recent decade, house prices and for instance GDP might be expected to fall more than in Denmark and the Baltics, which faced substantial house price declines in the crisis.

We compute exposure-weighted scenarios for each of the four major banks. The scenario growth rate of house prices for bank A is computed as Bank A's exposure in Sweden times Swedish house price growth, plus Bank A's exposure in Norway times Norwegian house price growth, plus the same product of exposures and house price growth in Bank A's other countries of counterparties, and divided by Bank A's total exposures in all countries. The same exposure weights are applied to other macroeconomic variables.

The exposure-weighted scenarios cannot capture the fact that some Swedish firms are active internationally. Loans to internationally active firms headquartered in Sweden (but operating globally and/or importing and exporting) are still subject to the Swedish scenario. Furthermore, such corporates would also be influenced by currency fluctuations. The Riksbank lacks the data to take global activities of corporates into account.

Risk-weighted assets

The Common Equity Tier 1 (CET1) capital ratio is one of the outcome variables of interest in the stress testing exercise. The CET1 ratio requires an estimate of risk-weighted assets (RWA) from the scenario. The Riksbank framework for credit risk differs from other frameworks that directly model the probability of default (PD) and loss given default (LGD) of bank borrowers – such frameworks allow for computing risk-weighted assets directly using the Basel approach for capital requirements.[43]

Risk-weighted assets can either increase or decrease in a stressed scenario. On the one hand, some borrowers default, and those exposures are removed from banks' balance sheets. Risk-weighted assets will therefore decline. On the other hand, remaining (performing) exposures are likely to migrate to higher risk categories. For instance, corporates and households suffer from reduced cash flows increasing the *risk* of defaults. In addition, falling asset prices increase losses given default.[44]

[43] See Basel Committee on Banking Supervision (2005, 2017). In addition to PD and LGD, estimates of credit conversion factors (CCF), asset correlations (R) and effective maturities (M) are needed to compute risk-weighted assets for credit risk, which together with risk-weighted assets for market and operational risk define total RWA.

[44] The banks' internal models use so-called downturn LGDs, which are the losses (given default) during an economic downturn. Since LGDs move (inversely) with asset prices and might be low prior to a recession, the downturn LGD assumption avoids large swings in LGDs (and in turn RWAs) due to falling asset prices in a recession. Since the implementation of internal models for capital requirement purposes,

The Riksbank's stress test includes both channels. First, risk-weighted assets from credit risk are reduced by the full amount of credit losses. This implicitly assumes that LGD and risk-weights are the same for the defaulting exposures.[45] This is a simplifying assumption; actual LGDs and risk weights for defaulting exposures might be different. Second, the Riksbank assumes that average risk weights for credit risk increase by 7.5 per cent in the first and the second year of the stressed scenario to capture risk migration. An increase by 7.5 per cent is probably on the low side, given that risk weights depend on PD and LGDs in a non-linear way: small increases in the probability of default imply substantially higher risk weights.

Whether risk-weighted assets will increase or decrease depends on the scenario, and the credit losses from the scenario. Linking the migration of risk weights to the scenario is one of the future developments the Riksbank wants to pursue. In addition, models for market and operational risk related to a scenario are left for future development. For now, risk-weighted assets for market and operational risk are kept constant over time.

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residential and commercial real estate prices in Sweden have been mostly rising, causing some concerns over the appropriate level of downturn LGDs.

[45] RWA should be reduced with the entire exposure, multiplied by its original risk weight. An exposure with a risk weight of 25 per cent reduces RWA by 0.25*Exposure. If the default gives a loss of LGD = 25 per cent, reducing RWA by the loss is the correct approach.

Appendix A3 Net interest income and net fee and commission income

Net interest income and net fee and commission income are the two most important income sources for the four major banks in Sweden. In the stress testing exercise, both income statement items are linked to the macroeconomic variables specified in the scenario.

Net interest income equals the revenue from charging interest on loans (the largest item on the asset side of bank balance sheets), minus the interest expenditure on deposits, covered bonds and other sources of funding. Net fee and commission income consists of fees related to payments, lending and deposit fees (such as fees levied on credit cards or bank accounts), commissions on transactions of securities (such as buying and selling of shares through the bank), mutual fund fees, insurance and pension activities and advisory and consulting services, minus any expenses related to these activities.

We normalize both items by total assets, and thus model the net interest margin (NIM) and net fee and commission margin (NFCM) as a function of macroeconomic variables. Our modelling strategy is to use a dynamic panel regression approach to directly estimate the correlation between NIM/NFCM and a set of selected macroeconomic variables. This approach is widely used by many peer authorities, such as Deutsche Bundesbank (DB) and the European Central Bank (ECB), and can be done with publicly available data from banks' quarterly reports. The estimated model parameters are then used to project bank-specific NIM and NFCM given the scenarios.

Dynamic panel regression model for NIM and NFCM

We estimate two separate regressions for the net interest margin and the net fee and commission margin. Both regressions are estimated with quarterly data from 2004:Q1 until 2018:Q4, and use the same estimation technique. We use the following regression model:

$$y_{it} = \mu_i + \alpha y_{it-1} + \beta X_t + \gamma z_{it-1} + \varepsilon_{it} \quad (1)$$

In equation (1), y_{it} is either the NIM or NFCM for bank i in period t, y_{it-1} is the lagged dependent variable, X_t is the vector of macroeconomic variables, z_{it-1} are bank-specific variables, μ_i is a bank fixed effect and ε_{it} is an idiosyncratic term. We include the NIM/NFCM in the previous quarter, as both income statement items evolve rather slowly over time, and the time series are therefore rather persistent. The bank-specific intercepts capture different business models between the different banks.

Since the inclusion of the lagged dependent variable and fixed effects may lead to biased and inconsistent estimates due to the correlation between the lagged dependent variable and the error term, equation (1) is estimated using a generalised methods of moment (GMM) estimator (Arellano and Bond, 1991).

The two regression models differ in the choice of macroeconomic variables.[46] For NIM, the macroeconomic variables include the growth rate of real GDP, the rate of inflation, the short-term interest rate (3-month sovereign yield), and the slope of the yield curve (the difference between 10-year and 3-month sovereign yields). GDP and the inflation rate capture the state of the business cycle, as we expect good economic conditions to lead to rising incomes, possibly stemming from increased lending and deposit activities. The inclusion of both the short and long interest rates is motivated by the fact that banks engage in maturity transformation by borrowing with short maturities and lending with long maturities,

[46] The choice of macroeconomic variables is based on the empirical literature (such as Albertazzi and Gambacorta (2009) and Dees et al (2017)), as well as on empirical grounds. Given the short series, we want to find a parsimonious regression model which fits the data relatively well. A least angle regression (LARS) algorithm (Efron et al. (2004)) supported the selection of variables included in the model.

and earn money from spreads. All these variables are lagged one quarter, as it may take some time for changes in the macroeconomic conditions to affect banks' business activities.

For NFCM, the macroeconomic variables include the growth rate of real GDP, the rate of inflation, and the return on the OMX stock index. Again, GDP and the rate of inflation capture the state of the business cycle, as we expect more revenues in good economic times. The stock market return directly captures securities income, as we expect asset under management fees to increase when returns are positive, as well as more stock market transactions on which banks earn commissions. Except for the stock market return, the variables are lagged one quarter.

To capture reputation effects, both models include the banks' equity ratio, which is the ratio between book equity and total assets.[47] We expect funding costs to increase and investment banking activity to decline (for instance due to mutual fund outflows) for low-capitalized banks, resulting in lower net interest incomes and lower net fee and commission incomes. Including the equity ratio is a parsimonious way to capture potential amplification effects stemming from a decline in equity in an adverse scenario.

To account for seasonal effects, the dependent variable is smoothed by computing the 4-quarter moving sum divided by 4-quarter average total assets. Similarly, real GDP and the rate of inflation (CPIF) are annual (Y/Y) growth rates. The equity ratio is also averaged over the last 4 quarters.

The dynamic panel regression approach requires only historical data on net interest income, net fee and commission income, total equity and total assets. The data comes from banks' quarterly reports. The macroeconomic variables come from Statistics Sweden and Macrobond.

Regression results

Figure 4 to 7 show the net interest margins (in blue) and net fee and commission margins (in red) for each of the four banks. The historical outcomes are drawn with straight lines, whereas the model fit is drawn with dashed lines. The regression models fit the data well, both over time and across banks.

The lagged dependent variable is highly significant in the model. Incomes are fairly persistent over time, and the model captures this well by including the lag of the outcome variable. As expected, higher equity ratios are associated with higher income margins. Banks with more capital have higher net interest income, in line with reputation effects.

Among the macroeconomic factors, the lagged value of the slope has the most explanatory power for the NIM. The correlation between those two variables is negative, which is not in line with the findings in many previous studies,[48] where the sign is usually estimated to be positive. This contradiction can be attributed to the different business model (in terms of funding structure and asset maturity) of the four major banks in Sweden compared with other banks that depend more on deposit financing and issue fixed-rate mortgages. On the asset side, the majority of the mortgage loans in Sweden have short interest-rate fixation periods (usually 3-month).[49] On the liability side, the Swedish banks are highly dependent on market financing. During the past ten years, market funding has consistently accounted for around 50 per cent of the total liabilities for the four major banks, among which 70 per cent are long-term liabilities (e.g. covered bonds and senior unsecured debt).[50] This may partially explain why the correlation between NIM and the slope of the yield curve is lower than in other studies.

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[47] The equity ratio of Swedish banks is very similar to the Basel III leverage ratio, despite slightly different definitions. The model includes the difference between the equity ratios in quarters $t-2$ and $t-1$.

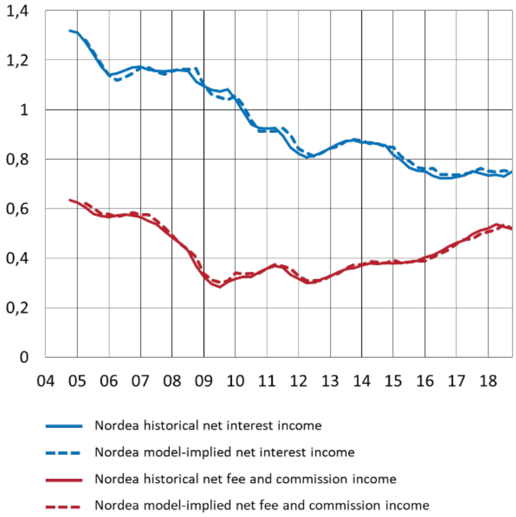
[48] E.g. Borio et al. (2015), Claessens et al. (2018), CGFS (2018), Dees et al. (2017)

[49] According to Statistics Sweden, around 70 per cent of newly issued mortgage loans in Sweden have interest-rate fixation periods equal to or shorter than 3 months, which has led to an increase of the proportion of floating-rate mortgage loans in the total mortgage stock from 35 per cent (2004) to 68 per cent (2018).

[50] The (fixed) interest payed to covered bond investors are typically swapped to floating rates to match the short fixation periods on mortgage loans.

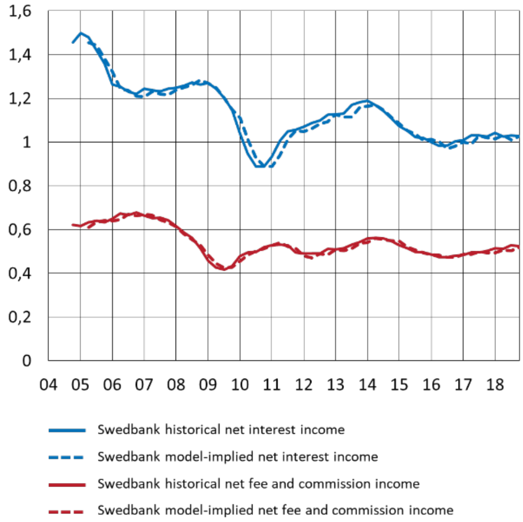
As expected, the level of the short rate has no impact as banks set deposit and lending rates as (relatively constant) mark-ups over the short rate. The zero lower bound on deposit rates, as we have seen in recent years, has been compensated by an increase in gross mortgage spreads.[51] The estimated coefficients for both the lagged real GDP growth and the lagged inflation rate in the regression for NIM are positive. This is as expected because a better macroeconomic condition can lead to more credit demand and supply and therefore an expansion of banks' interest-bearing business opportunities.

Figure 4 Nordea
Per cent of average total assets



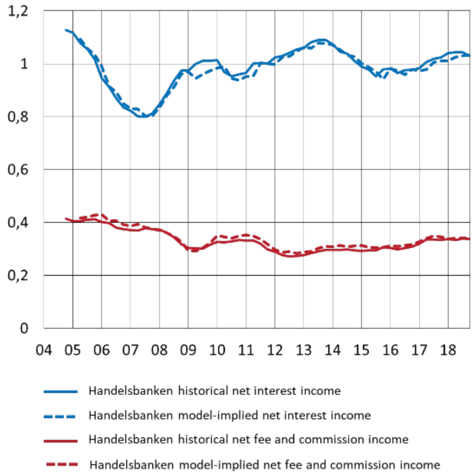
Sources: Bank reports and the Riksbank

Figure 5 Swedbank
Per cent of average total assets



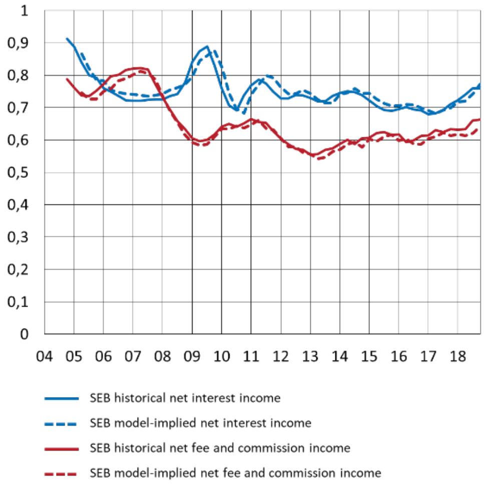
Sources: Bank reports and the Riksbank

Figure 6 Handelsbanken
Per cent of average total assets



Sources: Bank reports and the Riksbank

Figure 7 SEB
Per cent of average total assets



Sources: Bank reports and the Riksbank

The estimation results for NFCM are as expected and in line with the previous literature. NFCM is positively correlated with the real GDP growth and the inflation rate in the previous period, which is intuitive as a better economy may lead to an expansion of banks' financial

[51] The statistics on the gross mortgage spreads for banks in Sweden are available on the Finansinspektionen website.

services that generate fee and commission income. It is also positively correlated with the stock market return, which may reflect that there are more investment banking business opportunities (e.g. initial public offering, IPO) and more fee income associated with securities brokerage during stock market booms.

Scenario income

We use the estimated models to compile banks' income statements during a scenario. The scenario specifies paths for all the macroeconomic variables in the two regression models. As the models include the lagged dependent variable, we dynamically update the estimates of the net interest margin and net fee and commission margin.

The scenario does not specify a path for the banks' equity ratios, as it will depend on banks' earnings and credit losses. Instead, we recompute banks' equity ratios after every quarter in the scenario (using the estimated credit losses from the credit risk model to update equity and total assets) to forecast the income margins. The last step is to translate the margins into incomes in SEK, which can be done by multiplying by the 4-quarter average of (scenario) total assets.

The income statement of the banks contains additional items not discussed so far. First, operating profit includes revenue sources different from interest and fee and commission income, as well as operating expenditures (mainly staff costs). The maintained assumption is that these other items are unchanged relative to the last full year before the start of the scenario. For instance, staff costs in the years 2019 – 2021 are equal to staff costs under 2018.[52]

Gross profit is computed by subtracting the estimated credit losses from operating profits. Net (after-tax) profit is equal to the product of the bank-specific income tax rate and gross profit; taxes are set to zero if the bank makes losses. Finally, we assume the bank maintains its dividend policy specified in its public reports to estimate dividend payments and retained earnings.

Taxes in the scenario

The Swedish corporate tax rate is 22 per cent. However, the banks often have effective tax rates different from the Swedish statutory rate, as taxation occurs in the jurisdiction where business activity takes place. For simplicity, the Riksbank's stress test assumes that tax rates (i.e. the ratio between taxes and pre-tax profits recorded in the income statements) in the scenario equal the average of the tax rates in recent years. This gives tax rates around 22 per cent. The tax rates are set to zero if the bank makes losses.

Dividend payout policies

The banks announce their dividend payout policy on their websites. The Riksbank's stress test combines payout policies from end-2018 with historical payout ratios to formulate scenario dividend payout ratios. The assumed payout ratios range between 69 and 79 per cent. Dividends are paid out only when after-tax profits are positive. Hence, banks build up capital equal to one minus the dividend payout ratio times net profits if profits are positive, and experience capital declines when net profits are negative.

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[52] Some care is taken to remove non-recurring items on either the cost or income side for the latest year before the scenario. An example is the sale of credit bureau UC during 2018 yielding one-off incomes for the four major banks in Sweden.

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Appendix A4 Second-round effects: contagion and asset fire sales

The modules discussed hitherto look at banks' credit risk and earnings capacity in a given scenario. Increases in credit losses and lower earnings are standard elements of a stress test aiming to assess the soundness of individual institutions. However, looking at banks in isolation can underestimate the financial stability risks. As often emphasized in the Riksbank's Financial Stability Reports, the Swedish banking system is interconnected, which can amplify the risks in an adverse scenario. Risks related to interconnectedness are often termed 'second-round effects' in stress tests, as they come on top of standard credit risk and earnings stress tests.[53]

The Riksbank's stress test includes two modules to quantify the effects of an interlinked banking system: contagion and asset fire sales. First, banks have exposures towards each other through interbank lending. Interbank exposures are not necessarily bad for financial stability, as they help smooth out liquidity differentials between banks. For instance, one bank might have excess reserves available, and another might need liquidity to settle payments. An interbank loan is an efficient way to reallocate funds within the banking sector and manage funding liquidity risks. However, when interlinkages grow large, distress in one bank can spread to other banks through the same interbank exposures. In the worst case, a bank cannot repay its interbank counterparties, and the lending bank suffers a loss. We capture this phenomenon through a model of contagion where banks could make losses on their unsecured loans to other banks.[54]

Second, banks are exposed to similar asset markets. Banks are active in international financial markets to trade liquid instruments, and hold such instruments on their balance sheet for liquidity purposes. The reasons for doing so are broad, and include the need to satisfy liquidity regulations such as the liquidity coverage ratio (LCR) and net stable funding ratio (NSFR), as well as to earn profit from trading. Regardless of the reason, the fact that many banks are exposed to the same or similar asset classes increases the risk of transmitting distress via asset prices. We capture this phenomenon through a model of fire sales. We discuss the contagion and asset fire sale models next.

Contagion

Exposures between the Swedish banks are large, and such exposures are one way that stress in one bank can spread to another bank. In order to capture this, the Riksbank's stress test integrates the framework presented in Espinosa-Vega and Solé (2011).[55] This method can be described as a domino game where failure of one bank gives rise to losses in other banks, which in turn can trigger failure of another bank.

On a quarterly basis, the four major Swedish banks report their 15 largest counterparty exposures, including both Swedish and foreign counterparties, to the Riksbank. The confidential data set includes positions in unsecured loans (sight deposits and overnight), securities (mainly covered bonds) and derivatives. The counterparty data does not include repo agreements and equities. For the contagion module, we isolate unsecured loans between the four banks participating in the stress test.

The contagion module requires a threshold to trigger the contagion between banks. The threshold chosen is a breach of the Basel-III leverage ratio minimum requirement of 3 per

[53] In addition to systemic risks stemming from interconnectedness, second-round effects also capture feedback between the financial sector and the real economy. One example is a reduction in credit supply (due to deteriorated bank balance sheets), which in turn leads to lower investment and lower GDP. The Riksbank's stress test for bank capital currently does not include a module to incorporate such feedback effects.

[54] Given the importance of the interbank market for liquidity management, interbank market stress (and perhaps even market freezes) are often included in stress tests of banks liquidity. The Riksbank's stress test for capital does not include aspects related to liquidity stress.

[55] In addition to credit risk, the framework described by Espinosa-Vega and Solé (2011) makes it possible to include a funding shock. However, since we have a framework for fire sales, this module will be limited to only capture the credit risk.

cent. If bank A breaches the 3-percent leverage ratio, it is assumed to default on outstanding loans to banks B, C and D. In turn, banks B, C and D suffer a loss, equal to the loan amount multiplied by the Loss Given Default (LGD) parameter. Since we only use unsecured exposures, the LGD parameter should be quite high, and it is set at 50 per cent.

The loss suffered by, for instance, bank B can have repercussions for the other banks (including bank A). If, for instance, bank B also breaches the leverage ratio threshold of 3 per cent, it also defaults on its interbank loans (with the same LGD of 50 per cent). Like a domino game, banks C and D can become the next parties to breach the threshold after realizing the losses from banks A and B.

The losses suffered from direct contagion are classified as credit losses, and hence come on top of credit losses from other counterparties (such as firms and households). In addition, the losses reduce total assets of the impacted banks. Given the confidential nature of the data, the Riksbank does not publish estimates of interbank positions or scenario losses.

Asset fire sales

Whereas the contagion module focuses on the transmission of shocks via direct exposures between banks, there are also indirect linkages between banks. For instance, all Swedish banks have significant exposure to the Swedish housing market. More generally, banks have correlated portfolios of assets. This similarity in asset holdings can give rise to fire sale dynamics.

Distressed banks might sell assets in order to keep satisfying capital requirements. When many banks are stressed at the same time and their portfolios are correlated, their selling of assets can affect market prices of these assets. As a result of falling asset prices, all banks suffer (mark-to-market) losses, even those that were not in distress initially. This is an example of a fire sale channel.

To quantify indirect contagion, data from the 2018 EBA stress test is used to estimate fire sale losses for the Swedish banks, in combination with the model outlined in Cont and Schaanning (2017). Besides the outcome of the stress test, the EBA also publishes bank-by-bank data on the exposures by asset class and country. These are mapped into liquid and illiquid assets, where liquid assets are sovereign, equity, covered bond, derivative and large corporate and institutions exposures. Remaining exposures (mostly real estate and retail) are considered illiquid.

Example of a fire sale channel

The following example describes how the framework works for Swedish banks. Suppose the shock is a house price shock in Spain – the Swedish banks are hardly affected by such a shock given the lack of meaningful direct exposures to Spanish households or construction companies. In contrast, Spanish banks are affected by this shock, and realize losses. Spanish banks might try to free up capital by selling assets, either illiquid (loans, etc.) or liquid assets (securities). As the Spanish banking sector is fairly big, the aggregate sales of securities held by Spanish banks might trigger price effects. These price effects are most prominent for markets where market liquidity isn't very deep. The selling of US treasury bills by Spanish banks will not have any significant price effect, but large volumes of Spanish corporate bonds sold can depress prices of such assets. As probably all Spanish banks are (more or less) exposed to the Spanish corporate bond market, the housing market shock becomes systemic as prices of bonds fall, creating mark-to-market losses for all Spanish banks.

For Swedish banks to be affected, it is necessary either that Swedish banks are holding Spanish corporate bonds, or that other market participants that have similar portfolios to the Swedish banks are affected. In other words, there might be German or French or Dutch banks exposed to the Spanish corporate bond sector, or there might be market spill-over effects where prices of Italian and French corporate bonds are affected as a result of the Spanish distress. The shock 'spreads north' and starts affecting prices of instruments held by Swedish banks. Depending on market liquidity, Swedish banks might well realize losses even though they have never been exposed to the initial shock. Furthermore, the process can iterate many rounds: should Swedish banks start selling assets, banks in other countries might be affected when their banks have similar portfolios to the Swedish banks, etc.

The distinction between liquid and illiquid assets is important: in the framework of Cont and Schaanning (2017), liquid assets can be sold if needed, whereas illiquid assets are firm-specific and have essentially zero resale value. This is an extreme assumption that could be relaxed, but it reflects the idea that loans to households and small and medium-sized enterprises are sticky, and banks have better information about their borrowers than outsiders.

The stress test data gives us stressed leverage ratios for each bank, at the start (end-2017) and after 1, 2 and 3 years of adverse conditions. On average, the leverage ratio declines by 64 basis points after 1 year. Some European banks fall below the 3-percent threshold.[56] This is the critical threshold maintained in the fire sale module: *banks that breach the leverage ratio requirement of 3 per cent will start selling liquid assets*. We assume that the leverage ratio after 1 year (implicitly) defines the initial shock to illiquid assets and capital.

The price effect of the selling of liquid assets by distressed banks depends on two factors. First, how much does each distressed bank sell? The model assumes that banks target a leverage ratio slightly above the minimum requirement, and will sell exactly enough assets to reduce their exposure for hitting the target.[57] Aggregating across affected banks then gives the quantity sold, by asset class and country. Second, the price impact function relates the quantity sold to percentage changes in prices. The model uses a parameter describing market liquidity of the assets. These market depth parameters are obtained from the Cont and Schaanning paper directly.[58] For example, market depth equals EUR 858 trillion for US sovereign exposures, and EUR 6 trillion for Swedish sovereign exposures. These numbers imply that the price of US sovereign assets falls by 0.0012 per cent for every EUR 10 billion of assets sold. For Swedish sovereign exposures, the corresponding percentage decline equals 17 per cent, reflecting the much smaller market for Swedish sovereign debt.

Combining the quantity sold with the price impact function gives an updated asset value for the banks possessing the asset. Note that the holders can be both banks affected by and banks unaffected by the initial shock: prices move for the asset, not for just one bank. We ignore the fact that banks can hedge against price movements by signing derivative contracts.

[56] Deutsche Bank, Norddeutsche Landesbank (DE), Banco BPM (IT), Bank Nederlandse Gemeenten (NL) all have (fully-loaded) leverage ratios below 3 per cent in the adverse scenario.

[57] If a bank needs to sell a given amount of liquid assets, it will reduce its sovereign, derivative, equity, covered bond and LC&I exposures proportionally to the initial positions. This proportionality assumption can be relaxed.

[58] We received the exact market depth parameters used by personal correspondence with the authors.

Such hedges can produce lower fire sale losses as long as the counterparty in the derivative contract is able to fulfill its obligations.

The updated values of liquid assets are used to update leverage ratios, by replacing initial liquid assets with the updated value of liquid assets after the sale. This in turn might drive some banks, who initially were just above the 3-percent leverage ratio threshold, to fall below it. It also further affects the already distressed banks, as banks do not internalize the price effect of their asset sales. In other words, the price decline reduces leverage ratios, and some banks will again have to sell assets, further generating price impact, yielding higher fire sale losses, etc. The process is iterated until convergence. The outcome of the fire sale module is thus a leverage ratio after fire sales, plus the numerator (Tier 1 capital) and denominator (total exposures) separately, bank by bank.

The EBA stress test includes 48 banks, among which the four banks participating in the Riksbank's stress test. Portfolio data on a further 138 European banks are available from the EBA 2017 Transparency Exercise. The transparency exercise data includes the same asset class-by-country exposure data as in the stress test, but lacks the leverage ratio under adverse conditions. For simplicity, adverse leverage ratios for the transparency exercise banks are generated using the average decline of leverage ratios for banks participating in the stress test, separately by country of headquarters when possible, or for all banks otherwise. The addition of these 138 banks does make a difference in practice, since more banks will be in breach of the 3-percent requirement, and a larger quantity of assets is sold, further depressing market prices.

For the Swedish banks, we use the EBA data on portfolios, but use the stressed leverage ratios (after running the credit loss model and earnings models outlined in this staff memo) from the Riksbank's stress test. The fire sale module is run only once, and kicks in as soon as one of the banks breaches the 3-percent leverage ratio threshold, or at the end of year 2, whichever event comes first. This is a conservative assumption, as it minimizes how much Swedish banks contribute to fire sale asset prices: in a scenario where leverage ratios for Swedish banks fall well below 3 per cent, running the fire sale model at the lowest leverage ratio would imply more deleveraging and higher losses for Swedish banks. We treat the fire sale loss as a reduction in the income statement item "net income from financial transactions", which is normally included as "net other operating income" in the Riksbank's stress test.

Results

The fire sale loss for Swedish banks depends on the scenario used. The scenario affects the starting point leverage ratios for Swedish banks (before the fire sale loss module is activated). For that reason, the results below are illustrative, and capture the isolated impact of fire sale losses, i.e. excluding any effect from the credit loss model or earnings models developed elsewhere in the staff memo.

The leverage ratio ranges between 4.5 and 5.2 per cent as of 2017-Q4. Leverage ratios decline somewhat for all four banks relative to these starting values, by between 2 and 23 basis points. This decline in the leverage ratio combines any impact generated in the EBA's stress test, which we argue is very small, with the price effects on financial assets held by the Swedish banks. The selling of distressed European banks in the EBA scenario can generate some impact on the Swedish banks. Although the impact on the leverage ratio is small (as both capital and exposures are reduced), the fire sale loss ranges between SEK 0.6 and 2.2 billion.

References

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