Staff Memo

Appropriate capital ratios in major Swedish banks – new perspectives

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This staff memo has been produced by members of staff from the Applied Research and Modelling Division and the Financial Policy and Analysis Division of the Riksbank's Financial Stability Department. The Department's responsibilities include promoting the stability and efficiency of the payment system through oversight, participation in regulatory work and the dissemination of information, and otherwise acting to prevent risks in the financial system.

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Summary[1]

In 2011, the Riksbank published a study on appropriate capital ratios for Swedish banks, in which the social benefit of higher capital ratios was weighed against possible social costs. Several factors suggest that the social benefits of higher capital ratios for banks may have been underestimated. One reason is that previous studies may have underestimated the expected cost of a crisis to society. The sluggish economic recovery has shown that the effects of the most recent global financial crisis have been serious and created greater social costs, not least in Europe, than studies have shown previously. In addition, earlier studies may have overestimated the long-term social costs of higher capital ratios for banks. Several new studies have also concluded that higher capital ratios may be justified.

In light of this, the Riksbank has made new calculations of appropriate capital ratios, which are presented in this staff memo. We proceed from the same conceptual framework as the Riksbank Study from 2011, but we now focus on the leverage ratio (equity to total assets) instead of measures of risk-weighted capital. We also take into account new research published since 2011. In our analysis, we balance the expected social costs of higher capital ratios against the expected social benefit. The cost is based on the possibility that higher capital ratios may increase the banks' funding costs. If banks transfer these costs to their borrowers then the level of GDP could be negatively affected. Nevertheless, this cost must be weighed against the benefit of the reduced probability of banking crises when banks have more capital as a buffer against large losses. This is valuable as crises can be very costly for society.

Our calculations indicate that higher capital ratios than those currently observed for the major Swedish banks would have a limited social cost, at the same time as we assess that a reduced risk of a Swedish financial crisis could be expected to generate a social benefit. All in all, this means that even a relatively minor reduction in the probability of a crisis could be enough to justify higher capital ratios than those that the banks currently have.

Depending on the assumptions made, the calculations provide support for an appropriate capital level in relation to total assets for major Swedish banks to be somewhere in the interval of 5 to 12 per cent. The calculations do however involve a large amount of uncertainty.

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Appropriate capital ratios in major Swedish banks – new perspectives

In 2011, the Riksbank published a study on appropriate capital ratios for Swedish banks. The study deemed an appropriate capital ratio to be between 10 and 17 per cent of risk-weighted assets. At the end of 2011, Swedish authorities decided that the major Swedish banks were to have a minimum Common Equity Tier 1 (CET1) ratio of 12 per cent of their risk-weighted assets.

Several factors suggest that previous studies of appropriate capital ratios may have underestimated the social benefits of higher capital ratios. One reason is that these studies may have underestimated the likely cost of a crisis to society. The sluggish economic recovery, not least in Europe, has over time shown that the latest financial crisis has created large social costs. Moreover, countries with well capitalised banks have been found to recover better after crises (Jordà et al, 2017). In addition, previous studies, such as BCBS (2010), may have overestimated the negative effect of increased capital ratios on banks' funding costs and ultimately the cost for companies to fund productive investment. Several new studies, such as Dagher et al. (2016), Federal Reserve Bank of Minneapolis (2016) and Firestone et al. (2017), find that high capital requirements may be socially beneficial.

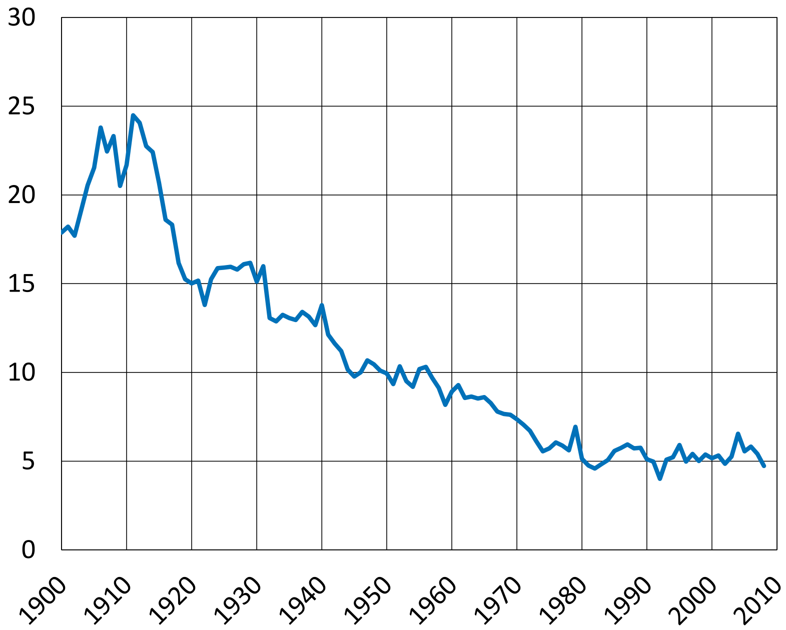
For Sweden, the negative effects of increased capital requirements have been limited. Banks' profitability has continued to be good and lending has continued to be expansionary. For Swedish banks, higher capital requirements have coincided with a reduction of their risk weights and thereby a limited increase in capital in relation to their total assets. This might be one reason for their continued good profitability and strong lending. The use of internal methods to calculate capital requirements has over time led to lower risk weights, which increases capital adequacy for a given amount of capital. But, even though the risk-weighted capital ratios have risen, the banks have probably not increased their resilience to the same extent. In this study, we therefore focus on the leverage ratio instead of risk-weighted capital measures.

Against this backdrop, in this publication, we present new calculations of appropriate capital ratios for the major Swedish banks. The analysis is based on the same conceptual framework as Sveriges Riksbank (2011) but considers new research in the field since 2011. Based on the assumptions made in the study, the calculations finds an appropriate level for the leverage ratio of major Swedish banks to be somewhere in the interval of 5 to 12 per cent. Because our results are based in part on data from a period in which there were no risk weights for Swedish banks assets, a direct translation of our leverage ratio to risk-weighted capital ratios is not straightforward to interpret. The estimated interval for the leverage ratio would, translated using current risk weights, imply a capital level in relation to total assets of about 25-60 per cent of the major Swedish banks' risk-weighted assets.

Why are capital requirements needed for banks?

The major Swedish banks fund their operations with a large share of debt compared with other companies that obtain funding to a greater extent using equity. Chart 1 shows that Swedish banks' equity as a proportion of total assets is low from a historical perspective. Their equity currently amounts to about five per cent of total assets.

Chart 1. Swedish banks' equity as a share of total assets, 1870-2008
Per cent



Source: Hortlund (2005, 2008)

For the banks' shareholders, high leverage can provide high returns on equity in good times. The drawback is that the banks' ability to handle large losses deteriorates when equity only constitutes a small part of the total funding. The higher the leverage, the riskier the bank's operations are – both for those funding the bank and for society as a whole.

Banks provide important functions in the economy and if a single bank encounters problems, it risks causing extensive shocks in the rest of the economy. In addition, the major Swedish banks are interconnected, partly because they own each others' covered bonds and are exposed to the same sectors, which means that problems in one bank risk spreading to the others.

If a bank does not consider the indirect and direct effects that its risk-taking behaviour may have on the economy, it may take excessively large risks from society's perspective. This follows from the bank not bearing the full cost when the risk it takes results in a bad outcome. The appropriate level of banks' equity is therefore probably higher from society's perspective than from the banks' own perspective.[2] Therefore, capital requirements aimed at ensuring that banks hold a certain minimum level of equity may contribute to a more efficient resource allocation.[3,4]

Cost and benefit of higher capital levels

What constitutes an appropriate level of banks' equity from society's perspective can be analysed in different ways. For example, stress tests can be performed to assess what capital

[2] Sveriges Riksbank (2011).
[3] For a more detailed discussion of the purpose and functions of capital adequacy, see Berger et al. (1995).
[4] Capital requirements can be designed in many ways, including different combinations of minimum requirements and buffers. How capital requirements should be designed is beyond the scope of this staff memo.

ratios are appropriate in order for the bank to be able to withstand different types of shock. In this study, we have instead approached the question in the same spirit as the Basel Committee's *Long-term Economic Impact Study* from 2010 and the Riksbank study *Appropriate capital ratios in major Swedish banks* from 2011, hereinafter referred to as BCBS (2010) and Sveriges Riksbank (2011) respectively. These two studies use a conceptual framework where any expected social costs of higher capital ratios are weighed against the expected social benefit.

The social cost is due to the fact that higher capital ratios can increase banks' funding costs. If this is the case and banks pass on the cost increase to their customers, it will become more expensive to borrow from banks, which can lead to reduced investment and lower GDP.

The social benefit comes from the reduced probability of a banking crisis if banks hold more equity that can constitute a buffer in the event of major unexpected losses. This is of great value as banking crises can be very costly for society.

The difference between the cost and the benefit gives us the social net benefit. By calculating cost and benefit at gradually higher capital ratios, we can form an opinion on how the marginal social net benefit develops, i.e. how the net benefit changes if we add more equity at different levels of the capital ratio. The conceptual framework is summarized in Table 1.

Table 1. Conceptual framework

Social cost and benefit of higher capital ratios for banks
(-) Cost
More equity can increase banks' funding costs → More expensive to borrow from banks → Lower GDP
(+) Benefit
More equity reduces the probability of a financial crisis
A financial crisis is costly for society
(=) Net benefit for society

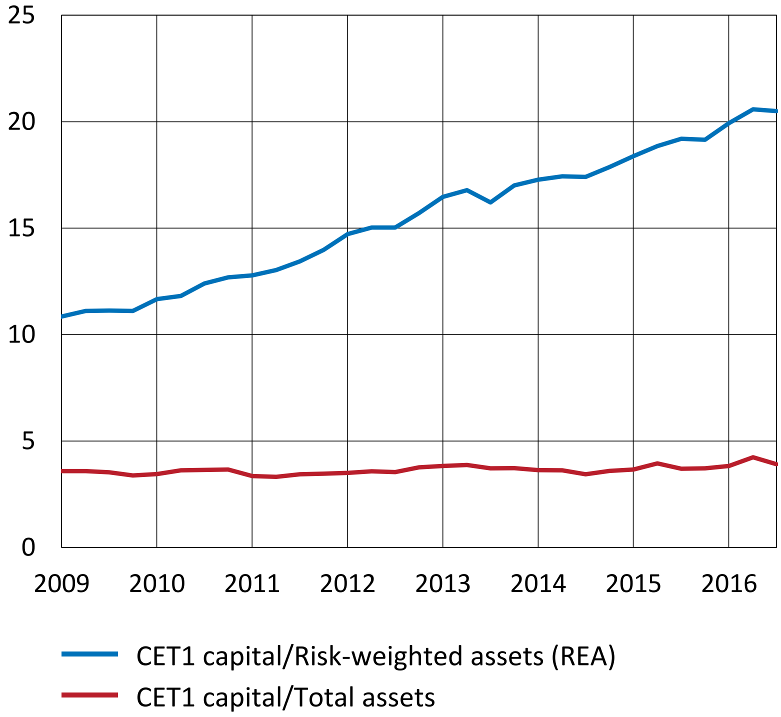
Source: Own example based on Table 1 in Fender and Lewrick (2016)

When the capital ratio is increased, the net benefit from further increases gradually declines. At some level the probability of a crisis no longer decreases enough to offset the costs that may result from further increases in the capital ratio. As long as a further increase provides a benefit that is at least as large as the costs, raising the capital ratio is justified in terms of the net benefit. The question we ask ourselves is at what level the social costs would outweigh the social benefit of a further increase in capital ratios.

Our calculations focus on equity in relation to total assets, i.e. what in a regulatory context is referred to as a bank's leverage ratio. The Basel Committee has agreed on a measure of the leverage ratio that relates a bank's Tier 1 capital to its exposures. Calculating a bank's exposures involves items both on and off the balance sheet. Due to the lack of historical data for this measure we do not use it for our calculations. Instead we focus on the book value of capital in relation to total assets on the balance sheet. For the major Swedish banks these two different measures currently differ only marginally. Several previous studies, such as BCBS (2010) and Sveriges Riksbank (2011), focus on capital in relation to risk-weighted assets rather than the leverage ratio. However, Swedish banks' risk weights have changed relatively quickly making the studies above difficult to interpret. Chart 2 shows that the banks hold far more equity in relation to their risk-weighted assets than previously. At the same time, their equity as a share of total assets has hardly increased at all. The reason for this is that the major banks have reduced their risk weights considerable in recent years. This suggests that banks probably have not increased their resilience to the same extent as the risk-weighted capital ratio has.[5]

[5] See Sveriges Riksbank (2015), Finansinspektionen (2014).

Chart 2. Capital ratios in Swedish banks, 2009-2016
Per cent



Source: Banks' interim reports and the Riksbank

In the next section, we provide a brief description of how the cost and benefit of higher capital ratios can be calculated. The calculations are presented in more detail in Appendices A-E. First, we analyse the social cost and then the social benefit. After that, we weigh the cost against the benefit at different capital ratios.

Equity is more expensive than debt but makes banks less risky

In this section, we analyse whether higher capital ratios increase the cost of credit and, if so, how large such an effect may be. Equity is usually a more expensive form of funding than debt. This is because equity is normally riskier.[6] However, it is not self-evident that the bank's total funding costs will increase if the proportion of equity to total assets increases.

The so-called Modigliani-Miller theorem says that, under certain assumptions, a company's total funding cost is not affected by how it mixes equity and debt to finance itself (Modigliani and Miller, 1958). However, in practice, there are a number of frictions linked to a bank's funding that give reason to believe that the Modigliani-Miller theorem does not fully hold. Two central examples are briefly described below. For a more detailed discussion, see Appendix A.

Taxes are an example of frictions that could affect a bank's funding costs when the percentage of equity to total assets increases. The Swedish tax system allows tax relief for interest payment expenses but not for dividends to shareholders. When debt is replaced with equity, the bank foregoes a tax deduction corresponding to the interest expenditure for the debt multiplied by the corporate tax rate. But, as we are talking about relatively small increases of the bank's equity here, this only has a limited effect on a bank's funding cost. If a bank increases its equity to total assets by one percentage point (i.e. debt decreases by the same amount), it will forego a tax advantage corresponding to about 0.01 per cent, or one

[6] Shareholder return is not predetermined but depends on how much is left after the firm's lenders have received their agreed compensation. This could be said to apply both to current returns and in the event of bankruptcies. It is then reasonable to expect equity investors to demand a higher expected return than the return on debt, in compensation for the higher risk.

basis point, of the bank's total funding costs.[7] In addition, we can also note that, even if debt is treated more favourably in the tax code, this is not necessarily justified on economic grounds and can distort companies' funding decisions (SOU 2014:40; IMF, 2009). To the extent that capital requirements counteract distortions in the economy, the social cost of more capital can thereby be expected to be lower than the private cost for the banks.

Another relevant example of frictions is state guarantees, for example in the form of a deposit guarantee or the market's expectation that the government will protect the banks' lenders if the bank encounters problems. Such frictions can make debt funding cheaper than it would otherwise have been. Here, the distinction between private costs and social costs is particularly important. If the deposit guarantee or expectations of government intervention lead the banks to take greater risks than they otherwise would have, it may be socially desirable to have a capital requirement that limits risk taking. In this case too, the social cost may therefore be assumed to be lower than the private cost – or, even, to comprise a benefit and not a cost at all.

When a bank increases the percentage of equity, since equity is a more expensive form of funding than debt, one would expect an increase in the bank's funding cost. At the same time, since more equity constitutes a larger buffer against losses, the bank becomes less risky from an investor perspective and therefore the cost of financing with debt and equity decreases for the bank.[8] This effect, which is known as the Modigliani-Miller offset, thus to some extent counteracts the cost increase that having a larger share of equity entails.

Table 2 summarises the Modigliani-Miller offset from a number of studies. As shown in the table, estimations of this Modigliani-Miller offset are relatively large. An estimated effect of, for example, 40 per cent means that the estimated increase in banks' funding costs is 40 per cent lower than what would have been expected in the absence of this offsetting effect.

Table 2. Examples of studies finding a Modigliani-Miller offset

Study	Countries	Period	Estimated Modigliani-Miller offset (%)
ECB (2011)	54 global banks	1995-2011	41-73
Junge and Kugler (2012)	Switzerland	1999-2010	64
Miles et al. (2013)	United Kingdom	1997-2010	45-90
Shin (2014)	105 banks in developed economies	1994-2012	46
Toader (2014)	European banks	1997-2011	42
Brooke et al. (2015)	United Kingdom	1997-2014	53
Clark et al. (2015)	USA	1996-2012	43-100

Note. The calculated effect in column 4 states to what extent the cost of higher capital requirements is counteracted by the so called Modigliani-Miller offset. This offset causes banks' funding costs to increase less than what would otherwise have been observed. See Appendix A for a more detailed description of the table.

Although there is some Modigliani-Miller offset, higher capital ratios typically give rise to a cost increase for the banks. The next question is to what extent this cost is passed on to the banks' customers. In Table 3 below, we present an overview of international research that studies the extent to which higher capital ratios affect banks' lending rates.[9] The studies examine a variety of countries during different time periods.

[7] If we assume that the interest rate for debt funding is 5 per cent and that the corporate tax rate is 22 per cent, the tax effect of one percentage point of debt being replaced by one percentage point of equity corresponds to a cost increase for the bank of 0.05 x 0.22 x 0.01 = about 0.01% or just over one basis point. See also Hanson et al. (2011), who obtain similar results for banks in the United States.
[8] In the long run, this applies for both debt financing and equity. A party lending to a bank runs a greater risk of not getting the entire amount back if the bank holds a small proportion of equity. And a lower capital ratio in a bank means that, all else being equal, the bank's equity becomes more risky, as the value of equity then varies more over time and the risk of bankruptcy increases.
[9] The literature often refers to the effect on the lending spread. For simplicity, refer to the effect on lending rates.

Table 3. Studies estimating the extent to which the banks increase their lending rates if they increase equity to total assets by one percentage point

Study	Countries	Period	Increase in lending rates (bps)
BCBS (2010)	Selection of OECD countries	1993-2007	26
Junge and Kugler (2013)	Switzerland	1999-2010	0.7
Miles, Yang and Marcheggiano (2013)	United Kingdom	1997-2010	1.2
Bank of England (2015)	United Kingdom	1997-2014	25
Elliot (2009)	USA		20
Kashyap, Stein and Hanson (2011)	United States	1976-2008	3.5
Baker and Wurgler (2013)	United States	1971-2011	8.5
Cosimano and Hakura (2011)	Global	2001-2009	12
King (2010)	Selection of OECD countries	1993-2007	30
Slovik and Cournede (2011)	Selection of OECD countries	2004-2006	32
De Resende, Dib and Perevalov (2010)	Canada		2.5
Corbae and D'Erasmo (2014)	United States		50
Kisin and Manela (2016)	United States	2002-2007	0.3
Mean value			**16.3**

Note. To make a comparison between the studies easier, we make two simplified assumptions. Firstly, we translate the measure of risk-weighted capital to the leverage ratio on the basis of the assumption that the average risk weight is 50 per cent, which is to say that the risk-weighted assets amount to half of total assets.[10] Secondly, we rescale the estimated effect in each study to the effect of an increase in equity of one percentage point in relation to total assets. We assume then that the effect is proportional, which is to say that the effect of, for example, raising the capital ratio by two percentage points can be assumed to be twice as large as the effect of raising it by one percentage point. See Appendix A for a more detailed description of the table.

This research overview indicates that the banks' lending rates may be expected to increase if banks are forced to hold a higher proportion of equity, but the effect is modest. The studies in the table above suggest that, if banks increase their equity to total assets by one percentage point, lending rates can be expected to increase by about 16 basis points or 0.16 percentage points, on average. Part of the estimated effects in the table above may seem high in the context of the Swedish banking sector. A rough estimate shows that, all else being equal, Swedish major banks' average funding cost would increase by about 10-12 basis points if they were to replace one percentage point of debt with equity.[11] However, since banks' assets also consist of other assets than loans, lending rates must increase more than the amount suggested by the calculations above if the increase in funding costs is assumed to be passed along entirely in the form of increased rates on loans. See for example Firestone et al. (2017). In addition, many of the studies above also include indirect effects, e.g. impaired competitiveness between banks. It is an open question to what extent such indirect effects may be relevant for Sweden. All in all, we let the average of 16 basis points constitute our best assessment, but it cannot be ruled out that this overestimates the magnitude of the effect for Sweden. It should also be remembered that the question we are actually asking is not whether higher capital ratios increase the cost of borrowing from the banks' perspective, but what the effects could be for the economy as a whole. Companies wishing to fund productive investment could also be expected to borrow from other financial institutions, or to fund themselves with equity to a greater extent.[12] For both of these reasons, the effect on the cost of funding investments is expected to be lower than the effect on the banks' funding costs.

[10] Actual risk weights differ from country to country. Our assumption of 50 per cent is higher than the major Swedish banks' risk weights, which are about 20-25 per cent, but is in line with what can be observed in other countries – Swedish risk weights are low from an international perspective. Our assessment is that the assumption of an average risk weight of 50 per cent means that, while we over- or underestimate the effects in individual studies, on the whole, we are in the right ballpark.

[11] For example, if the capital cost amounts to 12 per cent and 2 per cent for equity and debt respectively, and if the corporate tax rate amounts to 22 per cent, the average capital cost increases by just over 0.1 per cent, or 10 basis points, if borrowed capital is replaced by equity to an extent corresponding to 1 per cent of total assets. This example does not refer to any specific bank or specific period.

[12] In this study we do not assess to what extent this can be expected to occur.

Banks' capital ratios can affect lending for investment

In the previous section, we noted that higher capital ratios can have some effect on banks' funding costs and that they might pass on the cost to their customers. If this occurs, it will become more expensive to borrow from banks, which may result in a lower GDP level in the long term. Put simply, a greater capital cost in the economy can mean that some investments that were previously profitable cease to be so due to the higher capital cost. Lower investments reduce the capital stock in the long run and thus, the level of production in the economy becomes lower.

To form an opinion on how large this GDP effect might be, we use the Riksbank's RAMSES macroeconomic model as well as a macroeconomic model that more explicitly considers the banking sector. Our calculations focus on how the economy is affected in the long term.

The macroeconomic model with a banking sector is taken from Iacoviello (2015) and calibrated to Swedish conditions. The model contains a capital requirement for banks, making it particularly appropriate for our purposes. To evaluate the effects of a higher capital requirement, we can change the value of the capital requirement in the model and study the effects on GDP. In line with many other studies, we disregard the short-term effects and focus on the effect of when the economy has attained a new equilibrium.

The strength of the RAMSES model in this context is that it is particularly well suited to study the Swedish economy.[13] However, there is no explicit capital requirement in the model itself. Instead, the effect of higher capital requirements is calculated indirectly in two steps. In the first step, the effect on the banks' lending rates is estimated given an increase in the capital ratio of one percentage point. Here, we use the mean value in Table 3 above, i.e. 16 basis points. In the second step, we increase the lending rate[14] in RAMSES to study the macroeconomic effects in the long term. For a more detailed description of the calculations, see Appendix B.

Table 4 shows that the two approaches provide approximately the same results. If we increase the capital ratio by one percentage point in relation to total assets, it is estimated in both cases to lead to a marginally lower GDP level in the long term (0.13 and 0.09 per cent respectively). Both models have different advantages and disadvantages. We therefore let an average of the estimations constitute our best assessment of the effect size, which is a common way of dealing with model uncertainty.

Table 4. Long-term effect on GDP of higher capital requirements
Effect on the level of GDP of increasing the capital requirement by 1 percentage point in relation to total assets

Model	Experiment	Effect on GDP level in the long term (per cent)
Iacoviello (2015)	Increase of capital requirement by 1 percentage point	-0.13
RAMSES	Lending rate increases by 16 basis points	-0.09
Mean value		**-0.11**

Note. See Appendix B for a more detailed description of the table.

The estimations in the table above indicate that capital requirements are only expected to have a limited effect on the long-term GDP level. In Appendix B, we compare our findings to similar results obtained for other countries in studies using a variety of methods.

Crises lead to large costs for society

Banking crises, and financial crises more generally, are very costly for the economy. It may therefore bring considerable social benefits if banks strengthen their resilience to crises by holding a larger proportion of equity.

[13] For a more detailed description of RAMSES, see Adolfson et al., 2013.
[14] Expressed more precisely it is a loan margin but for the sake of simplicity we refer to it as the lending rate.

A growing body of research seeks to estimate the social cost of a financial crisis based on historical experience. Based on more extensive analysis presented in Appendix C, we provide a brief account of this research here. Then we make an overall assessment of what a banking crisis would cost Sweden today.[15]

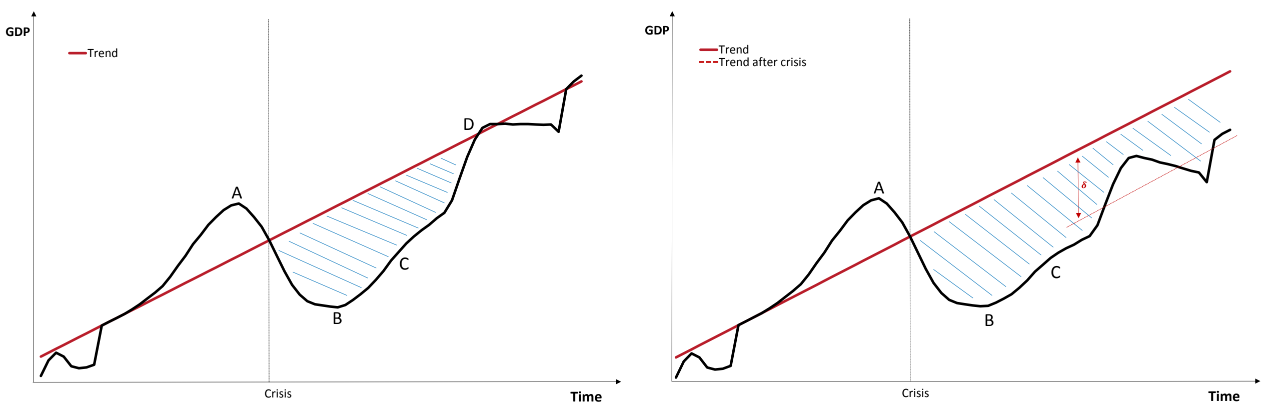
It is customary in the research to focus on the effects on output in the economy, i.e. the GDP level. But we should remember that the GDP effect of a crisis does not capture all aspects of how a crisis affects society. A crisis impacts households and companies to a varying extent. For example, some companies go bankrupt while others survive, or some individuals lose their job when unemployment rises. For those individuals most affected in a crisis, the effects can be very long-lasting. For example, their long-term chances on the labour market may deteriorate as a result of a protracted period of unemployment during the crisis, or because their company goes bankrupt. The effects of financial crises may also be borne to a larger extent by smaller parts of a country's population, which is why the welfare effects can be significantly greater than is indicated by the GDP effect. This can also contribute to long-term political effects with further negative consequences for society (Bromhead et al., 2009).

In the rest of the analysis, we ignore these aspects of crises, however, and concentrate on the effect on output, i.e. the level of GDP. The measure we focus on is the present value of the future GDP level being lower than what would have been the case without the crisis. We refer to this as the accumulated cost of a crisis.

The estimates of the accumulated GDP effect of a crisis differ considerably. The large variation reflects different historical experiences, different definitions of a crisis and different assumptions about the effect in the long term. Regarding the long-term effect, it is of key importance whether one assumes that the effect of a crisis is permanent or temporary. There is no consensus on this in academic literature, with both assumptions being common.

Figure 1 below shows two hypothetical examples of how GDP can develop before, during and after a crisis. In the first example, the effects of the crisis on GDP are temporary. In other words, the economy grows more quickly after the crisis than the long-term trend and hence returns to the original growth path. In the second example, the long-term growth rate is unaffected, but the economy does not regain the fall in GDP during the crisis as a result of an initial period of higher growth. Instead of the original growth path, the economy ends up on a parallel but lower growth path and output remains lower every single year compared to what it would have been without the crisis.

Figure 1. Two outlines of the effect of a crisis
Level of GDP



Source: Based loosely on BCBS (2010)

[15] It can't be ruled out that banks' capital ratios also affect the cost of a crisis. This is not incorporated in our analysis, where bank equity is assumed to only affect the probability of a crisis occurring.

In both cases, a social cost of the crisis is generated for as long as the level of GDP is below the original growth path. But in the first example, no further costs occur once the economy has completely recovered. In the second example, an additional cost is incurred every year after the crisis, as the economy does not reach the old path. The crisis therefore involves an interruption to economic development that is never recuperated.

The present value cost of the crisis, seen from the point in time when the crisis breaks out, is represented by the shaded area in each figure respectively discounted at a suitable discount rate. The fact that future costs are discounted reflects the perception that costs further ahead in time are less burdensome than costs that are close to the present – or, put another way, that people tend to value consumption today slightly higher than consumption tomorrow.

Table 5 summarises the findings from a number of studies that have tried to estimate the accumulated cost of a crisis. As shown in the table, the estimated mean value of the social cost of a crisis stretches from just over 8 to more than 300 per cent of GDP.[16] One reason for the relatively large spread in the estimates is that the time perspective differs between the studies. Most of them calculate an accumulated cost over time, but some only look at the effect during a few years following the onset of the crisis. Ball (2014), for instance, refers to the effect over a single year whereas others, such as Boyd et al (2005), also contain calculations of the discounted present value of the accumulated cost with an infinite horizon.

Table 5. Social cost of financial crises
Per cent of GDP

Study	Social cost			Assumption regarding long-term effect on GDP level
	Mean value	Min	Max	
Hoggarth et al. (2002)	**16**	0	122	Temporary
Laeven and Valencia (2008)	**20**	0	123	Temporary
Haugh et al. (2009)	**21**	10	40	Temporary
Cecchetti et al. (2009)	**18**	0	129	Temporary
Boyd et al. (2005)*	**97**	0	194	Temporary
Boyd et al. (2005)**	**302**	0	1041	Permanent
BCBS (2010)*	**19**	0	130	Temporary
BCBS (2010)**	**145**	0	1041	Permanent
Haldane (2010)	**268**	90	500	Permanent
Ball (2014)*	**8.4**	0	35	Temporary
Ball (2014)**	**180**	0	1035	Permanent

Note. The time perspective differs among the various studies. In most of the studies above, the effect refers to the present value of the accumulated cost, expressed as a percentage of GDP. A few of the studies calculate the accumulated cost over just a small number of years. Ball (2014) refers to the effect over a single year. In addition, the studies make different assumptions as to whether the effects of a crisis are temporary or permanent. Studies that include estimates with both temporary and permanent effects are marked with * or ** depending on which assumption is made. See Appendix C for a more detailed description of the table.

Since our study refers to capital ratios of Swedish banks, we are primarily interested in the expected cost of a banking crisis in Sweden. There is reason to expect a banking crisis to have relatively large negative consequences for the Swedish economy. In Sweden, banks have a major role in mediating credit to both households and companies. Mortgages are not securitised as they are in the United States for example, and the corporate sector funds itself to a greater extent via the banks rather than by issuing corporate bonds. Partly as a result of this, the Swedish banking system is large in relation to the size of the economy. In addition, it is concentrated and interconnected. Furthermore, the major banks have a high proportion of wholesale funding, a large part of which is in foreign currency. All in all, this makes the

[16] These estimations are from studies that differ with regard to methodology, crisis definitions, time horizon and what countries are studied.

banking system sensitive to shocks and means that a banking crisis could have significantly negative social effects.

To give us a rough picture of the conceivable effects of a Swedish banking crisis, we use the estimated cost of the Swedish banking crisis in the early 1990s. There are factors indicating that the effect could be both smaller and greater today, compared with the 1990s. On the one hand, Sweden now has a floating exchange rate, strong public finances and has implemented extensive structural reforms since the 1990s which have probably strengthened the resilience of the economy to crises. On the other hand, the banking sector is far bigger in relation to GDP now, about 350 per cent today compared with about 100 per cent at the beginning of the 1990s.

An additional factor to consider is the resolution framework, the intention of which is to take care of banks that either have failed or are close to failure. One aim of the framework is to provide better conditions for managing problems in a single bank by converting some debt into equity. However, the resolution framework is as yet untested and not until the next crisis will we be able to gain a clearer picture of the extent to which it can alleviate the effects of a banking crisis.

Boyd et al. (2005) estimate the cost of the Swedish 1990s crisis, expressed as the present value of a lower future GDP level, to be between 101 and 257 per cent of GDP. The lower figure stems from the assumption that the effects of the crisis are temporary, while the higher figure assumes that the effects are permanent. It is not obvious which of these estimates provides better guidance on how large the cost will be of a future Swedish crisis. As a result of this uncertainty and in line with how other studies have managed this uncertainty, we assess that an average of the two estimates could be a possible cost of a crisis in Sweden. This gives us a figure of 180 per cent of GDP, calculated as the present value of the GDP loss over time.

Table 6. Social cost of a Swedish financial crisis
Per cent of GDP

Source	Cost in per cent of GDP	Notes
The Swedish financial crisis 1990–1994		
Boyd et al. (2005),	101	Assuming temporary effect on GDP level
Boyd et al. (2005),	257	Assuming permanent effect on GDP level
Mean value	**180**	
International average		
Fender and Lewrick (2015)	100	
Ball (2014)	180	Present value calculation made by Fender and Lewrick (2015)

Note. The social cost refers to the present value of the accumulated GDP loss as a result of a financial crisis. See Appendix C for a more detailed description of the table.

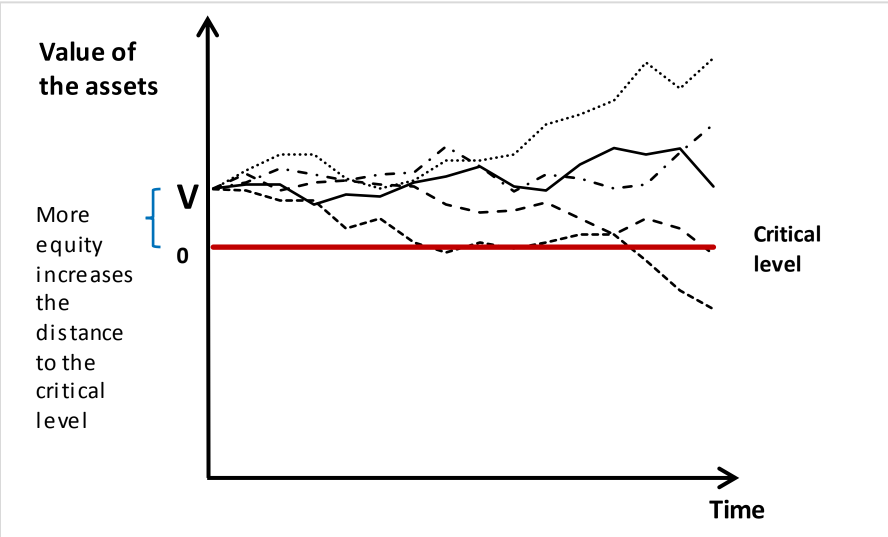
The assessment that a Swedish crisis can be expected to cost 180 per cent of GDP is slightly higher than the international average of 100 per cent calculated by Fender and Lewrick (2015). But there are circumstances that suggest that the effects of a banking crisis in Sweden would be greater than the international average, for example the Swedish banking sector's size and structure. A cost of 180 per cent can also be put in relation to the estimated cost of the latest financial crisis according to Ball (2014), who estimates that the financial crisis has resulted in a 8.4 per cent lower GDP level on average among OECD countries. If we assume the effect to be permanent and calculate the present value of this, the cost of a crisis will be 180 per cent (see Fender and Lewrick, 2015), i.e. a cost that is equivalent to our assessment for Sweden.

Equity reduces the probability of a crisis

As we stated above, the probability of a banking crisis decreases if banks have more equity that can constitute a buffer in the event of major unexpected losses. This is of great value as banking crises can be very costly for society. The next step is therefore to work out how much the probability of a banking crisis decreases if the capital ratio in banks is raised. To do this, we use two different models. The first is a standard model for credit risk, the so called Merton Model ("Model 1"). The second is based on banks' historical losses in order to estimate the probability of really large losses ("Model 2"). Here, we provide a brief description of our calculations. More detailed descriptions of the models can be found in Appendix D (Model 1) and Appendix E (Model 2).

The two models differ but are based on the same general idea. Banks have assets, the value of which varies over time. If the value of a bank's assets falls below a certain level, the bank may face serious problems as there is a considerable risk that it will not be possible to repay liabilities with the value of the assets. Regardless of where we set the critical level at which banks encounter problems, a higher proportion of equity initially means that the bank has a greater margin to the critical level. There is therefore less of a risk that the bank will encounter problems. The general idea is illustrated in Figure 2 below.

Figure 2. An illustration of a credit risk model



Source: The Riksbank

An important assumption is at which critical level banks can be expected to encounter serious problems. A bank can be considered insolvent if the value of its assets is lower than its liabilities. However, historical experience suggests that banks can have serious problems even when they are still solvent. Bank regulations reflect this by setting minimum requirements for banks' capital adequacy. For instance, banks can have problems with their liquidity as a result of a bank's debt falling due for payment before it has recuperated the money it has lent. The bank must therefore renew its funding several times during the loans' maturity period. If investors question the bank's ability to repay on any of these occasions, the bank may be forced to obtain funding at a higher cost or might not be able to renew the funding at all. As a result, the bank risks becoming illiquid. This can, in turn, mean that the bank is forced to sell assets quickly which can press down the assets' market value. As banks to a large extent are exposed to the same type of assets, other banks' balance sheets may also be weakened. This can exacerbate the negative spiral, a so-called *fire sale* problem (Schleifer and Vishny, 2011).

A relevant critical level of equity to consider is if a bank has disposed of large parts of its capital buffers and violates, or is close to violating, existing capital requirements. The bank then risks losing its license and may have difficulty to obtain funding, or could be put into resolution. There are no general regulations governing the level at which banks are put into resolution. In this study, we simply assume that the critical level is 1.5 per cent of total assets. This assumption is not to be seen as an interpretation of the supervisory authorities' criteria.

In addition, we also estimate Model 2 using a critical level of three per cent.[17] We also test, as in the description above, a critical level of 0 per cent, i.e., when the bank is insolvent so that its assets are not worth more than its liabilities.

When we show how higher capital ratios are expected to affect the probability of a banking crisis, it is important to remember that the social costs of a banking crisis are not necessarily uniquely connected to a bank becoming insolvent. Banks that, for example, lose some of their equity can prioritise restoring their capital ratios by quickly reducing their lending or sharply increasing their loan margins. In both cases, the bank's actions risk subduing both investment and consumption, thereby exacerbating the economic downturn. Countries with well capitalised banks tend to cope better with crises (Jordà et al, 2017). One explanation for this is that the transmission of monetary policy is likely to work better if banks have higher capital ratios (Gambacorta and Shin, 2016). These factors suggest that it can be relevant to consider higher levels for capital than those calculated in this study.

Model 1 – standard model for credit risk

The first model we use to estimate how the probability of a banking crisis decreases if we increase the capital ratio in banks (Model 1) is a standard model for credit risk based on Merton (1974). The starting point is that a higher proportion of equity gives the bank a greater margin for variations in the market value of the bank's assets before it approaches or falls below a certain critical level. The variation in the market value of a company's assets, known as volatility, cannot be observed in many cases. The model deals with this by using equity volatility, which can be estimated if a company's shares are traded on a stock exchange, to infer asset value volatility as priced by the market.

The Merton model is based on a number of simplifying assumptions, and therefore has certain limitations.[18] One of these limitations is that the model needs to be estimated from historical equity volatility and that data only captures the four major Swedish banks for the period of 1997-2016.[19] This risks underestimating the long-term probability of a banking crisis for at least two reasons. Firstly, volatility varies over time, and it is far from certain that historical volatility is a good indication of volatility in the future. If future volatility is higher than the average for the period studied, the model will underestimate the probability of a banking crisis. Secondly, the period studied does not cover the most serious banking crises that Sweden has experienced, including the banking crisis in the early 1990s. Both these factors suggest that the model probably underestimates the probability of a crisis.

The higher the volatility, the greater the probability of a banking crisis as an asset value with larger variation runs a greater risk of being below a critical level at some point in the future. To illustrate the effect different levels of volatility have on the computed probability of a banking crisis, the model is estimated for three plausible and historically observed levels of volatility: average, high and very high.[20] The model cannot predict which level provides the best guide for future volatility. Nevertheless, we note that the time period that we study has been largely characterised by moderate levels of volatility, but that the volatility in the future could very well turn out to be even higher.

To make a connection between the probability of a single bank encountering problems and the probability of a banking crisis breaking out, we assume that a banking crisis breaks out if for *any* one of the four major banks the value of its assets falls to the extent that its equity will fall below the critical level (which we, as above, assume is 1.5 or 0 per cent in this model). Although this is a simplifying assumption, it is commonly made in the literature and

[17] Neither is this to be interpreted as an assessment of when a bank can be put into resolution.

[18] We assume that the company has some form of borrowed capital and that capital markets are working entirely smoothly, i.e. there are no taxes, transaction costs or other obstacles. In reality, banks have a number of different forms of borrowed capital and a significant share of their funding is at short maturities, which creates liquidity risks that are not considered in the model. The model thereby probably underestimates the risk of banks encountering problems. Furthermore, we assume in the model that a bank only encounters problems if the market value falls below the critical ratio at the end of the time period to which the estimate refers, i.e. one year from now. If the market value falls below the critical ratio during the year, but then recovers, we then assume that the bank does not encounter problems. The probability of an individual bank encountering problems is thereby underestimated.

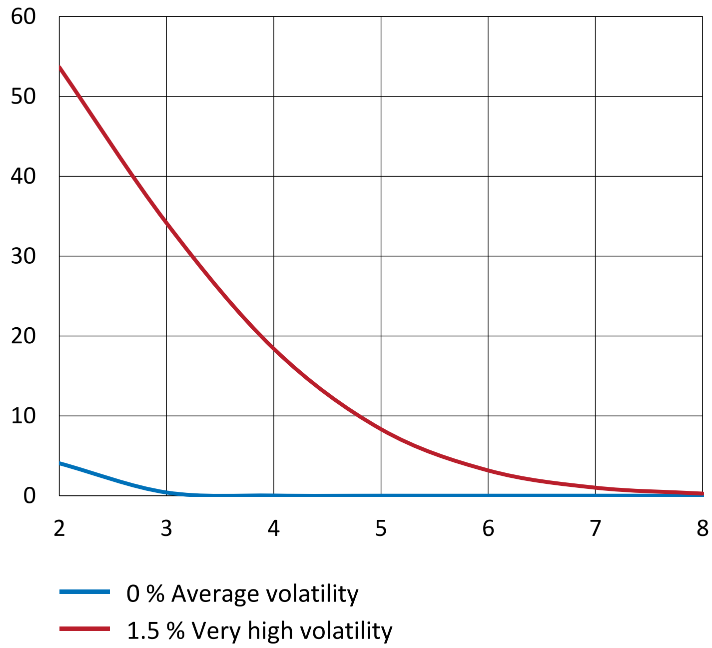
[19] The four major banks here refers to Nordea, SEB, SHB and Swedbank.

[20] The levels correspond to the 50th, 75th and 90th per centile respectively in the observed volatility 1997–2016. See Appendix D for a more detailed description.

appears reasonable given how closely interconnected Swedish banks are, in part because they own each others' securities. In addition, a crisis in one bank can create a crisis in other banks when lenders and depositors try to withdraw their money in a bank run. The same assumption is made in, for instance, Sveriges Riksbank (2011) and in a banking crisis model developed at the Bank of England (see BCBS, 2010, p 42). It cannot be ruled out, however, that this assumption in particular may overestimate the probability of a banking crisis. Set against this is the fact that we estimate the model based on the historical correlations for the four major banks. The fact that the correlations have been historically stronger in stressed periods reduces the significance of this assumption.

The probability of a banking crisis when the model is estimated based on historical volatility over the last 20 years is presented below. Chart 3 shows two examples in which the model is estimated assuming a) average volatility and a critical equity level set at 0 per cent of total assets (blue line), and b) very high volatility and a critical equity level of 1.5 per cent (red line). The x-axis shows capital in relation to total assets and the y-axis shows the probability of a banking crisis. The blue line shows that at capital ratios around two per cent of total assets the probability of a banking crisis is already relatively small (just over four per cent), falling close to zero at ratios over three per cent capital, on condition that the market value of the assets does not vary too much. The red line, which is based on very high volatility in the value of assets, shows that, at capital ratios around two per cent, the probability of a banking crisis is relatively high (about 50 per cent) and that the probability decreases as capital ratios rise.

Chart 3. Probability of a banking crisis one year ahead using Model 1
Probability at different capital ratios, in per cent



Note. The horizontal axis shows capital in relation to total assets and the vertical axis shows the probability of a banking crisis.
Source: The Riksbank

Table 7 below summarises the same information as the chart above but for six different combined assumptions about a bank's volatility and critical capital levels. The table indicates that the probability of a crisis is, as a rule, higher when assuming a critical capital level of 1.5 per cent of total assets compared with 0 per cent. The table shows further that the assumed value of asset volatility has a crucial impact on the estimated probability of a banking crisis is, in the sense that higher volatility implies a greater probability of a banking crisis.

Table 7. Probability of a banking crisis using Model 1
Probability at different capital ratios, in per cent

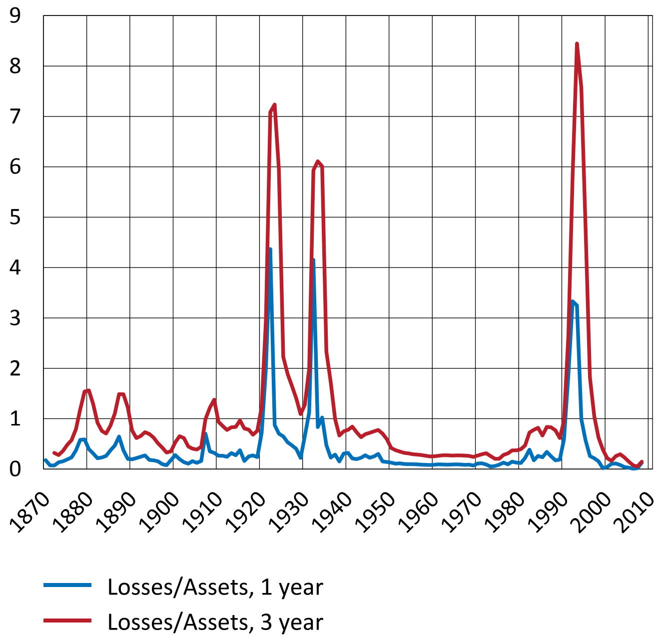
	Critical level 0 %			Critical level 1.5 %		
	Volatility			Volatility		
	Average	High	Very high	Average	High	Very high
2	4.06	13.12	25.61	35.54	45.61	53.66
3	0.40	3.79	12.66	9.89	21.55	34.16
4	0.02	0.79	5.25	1.40	7.34	18.41
5	0.00	0.12	1.82	0.10	1.80	8.34
6	0.00	0.01	0.53	0.00	0.33	3.16
7	0.00	0.00	0.12	0.00	0.04	1.00

Note. The first column refers to the capital ratio expressed as equity to total assets, in per cent.
Source: The Riksbank

Model 1 is a standard model that deals with the problem of not being able to observe the market value of a company's assets. But, as is often the case with models, it is sensitive to the assumptions made and the extent to which it provides good guidance on the probability of a crisis is an open question.

A comparison of the estimates above, which we have made using Model 1, based on the last 20 years of data, with a longer time series over loan losses in the Swedish banking system, suggests that the model can underestimate the risk of a banking crisis in Sweden. As Chart 4 shows, banks' historical loan losses are characterised by long periods of relatively minor losses alternating with less common but significantly larger losses, corresponding to 3-4 per cent of total assets over one year. In addition, years of very large loan losses tend to follow each other. On three occasions over the past 100 years, the banking system has demonstrated loan losses of about 6-9 per cent of total assets over a three-year period. This means that the probability of very large losses increases significantly when the time horizon is longer than one year. It is also important to remember that this data refers to the banking system as a whole. Individual banks have made larger losses over the same period.

Chart 4. Loan losses in the Swedish banking system 1870-2008
Loan losses as a share of total assets in per cent



Note. The chart shows loan losses during a single year and accumulated over a period of three years, respectively.
Source: Hortlund (2005, 2008) and the Riksbank's own calculations

Model 2 – estimating of the probability of losses based on banks' historical losses

As a contrast to Model 1, we also estimate an alternative model (Model 2) which to a greater extent considers banks' historical loan losses.

In Model 2, the banking system is represented as a single bank, i.e. we aggregate all the banks' assets and liabilities. We also assume that this bank makes a profit before loan losses that is constant in relation to the assets at the same time as it has loan losses that vary over time.[21]

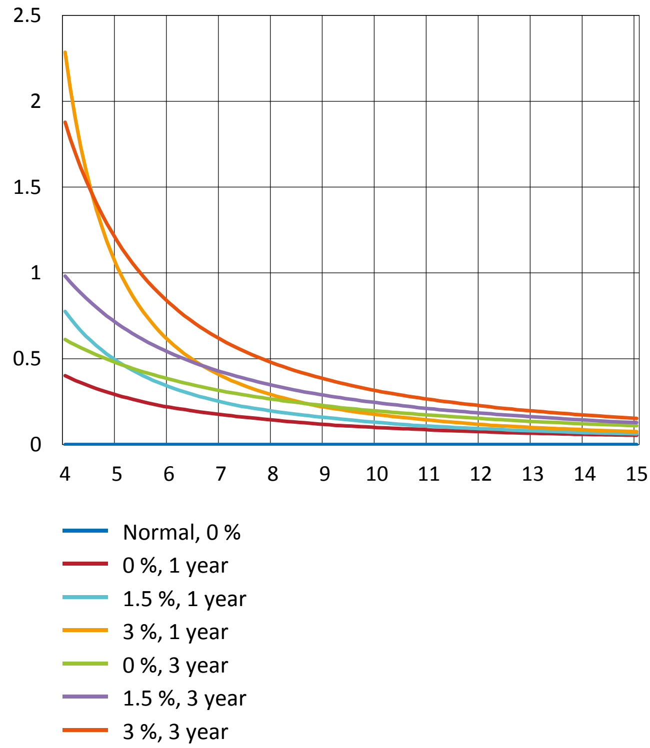
The time series in Chart 4 suggests that the probability of large losses is quite high. In terms of probability distributions, it is hence a distribution with "fat tails", i.e. a higher probability of extreme outcomes than the normal distribution. It is probably misleading therefore to describe the historical losses by using a normal distribution which implies that very poor outcomes would not be particularly likely. In Model 2, we therefore assume that the loan losses have a statistical distribution with a relatively high probability of very poor outcomes, known as a half-t distribution. See Appendix E for a more detailed description.

Chart 5 illustrates the estimated probability of a banking crisis according to Model 2. The chart shows the probability of a banking crisis one year ahead at different capital ratios. We have estimated the model based on historical losses not only one year ahead, which we also did in Model 1, but also three years ahead in order to take into account the fact that years with large losses tend to follow each other. As for Model 1, we have estimated the model using a critical level for equity to total assets of 0 and 1.5 per cent respectively. In addition, we estimated Model 2 using a critical level of three per cent of total assets. The latter is justified by the fact that the model refers to losses for the banking system as a whole and that the critical level is to be seen as an average. Individual banks can, however, have significantly higher losses than the average in a stressed situation and can therefore suffer a crisis before the average has reached the critical level. As we argue above, one bank encountering problems can be enough to spark a crisis throughout the entire banking system. This makes it appropriate to increase the critical level slightly to compensate for the risk of underestimating the probability of a banking crisis. It should not be seen as an assessment though of when a bank can be put into resolution due to it being deemed to have failed or is likely to fail. As a comparison, we also include an estimate of the model where we assume that the loan losses are normally distributed (dark-blue line close to zero).

Just as in Model 1, the probability of a banking crisis decreases as the capital ratio increases. The probability of a banking crisis is greater the higher the critical level is set (as a proportion of total assets) and higher when the probability is estimated based on losses over a three year horizon ahead instead of one year ahead (see Chart 5 and Table 8).

[21] This assumption is important in order to be able to calculate the extent to which losses during a crisis can be covered by profits. In practice, profits are not constant. One way for banks to manage major losses is to increase the rates they charge households and companies. If banks increase their rates in a deep recession, however, it risks exacerbating economic conditions.

Chart 5. Probability of a banking crisis one year ahead using Model 2
Probability at different capital ratios, in per cent



Note. Normal refers to an assumption on normal distribution. The percentages in the legend refer to different critical levels. 1 year and 3 years refer to historical losses 1 and 3 years ahead respectively.

Source: The Riksbank

Table 8. Probability in per cent of a banking crisis using Model 2 for different capital ratios
Probability at different capital ratios, in per cent

	One-year horizon			Three-year horizon		
	Critical equity level			Critical equity level		
	0 %	1.5 %	3 %	0 %	1, 5%	3 %
3	0.61	1.48	9.59	0.83	1.47	3.45
4	0.40	0.78	2.29	0.61	0.98	1.88
5	0.29	0.49	1.04	0.48	0.71	1.19
6	0.22	0.34	0.61	0.38	0.54	0.83
7	0.18	0.25	0.40	0.31	0.42	0.61

Note. The first column refers to the capital ratio expressed as equity to total assets, in per cent.

Source: The Riksbank

As can be seen in Chart 5 above, the use of Model 2 leads to a higher probability of a banking crisis compared with Model 1 at higher capital ratios. This is mainly due to Model 2 being estimated on a long time series that covers more historical financial crises while Model 1 is estimated using data from a shorter period in which loan losses have been relatively low.

Social net benefit of higher capital ratios

Finally, we add together the calculations described in earlier sections to get a sense of what may be considered appropriate capital ratio for major Swedish banks.

As described earlier, higher capital ratios generate social benefits by reducing the probability of a costly banking crisis. At the same time, there is a cost for higher capital ratios in that the GDP level becomes lower if banks' lending becomes more expensive. The net benefit for society of raising the capital ratios is the benefit minus the cost. By marginally increasing the capital ratios, one can calculate how this social net benefit will develop when further capital is added. To make it socially beneficial to raise the capital ratio, the expected benefit needs to exceed the expected cost.

How does one calculate the social net benefit?

In Table 9 we provide three stylised examples of how cost and benefit can relate to one another in order to illustrate how the net benefit can be calculated.

In this example, if the bank's equity at some level is raised by one percentage point, the probability of a crisis in this example declines by one percentage point. If the capital ratio is thereafter raised by an additional percentage point, the probability of a crisis declines by an additional 0.5 percentage points. If the capital ratio is raised by one more percentage point, the probability of a crisis declines further, by 0.1 percentage points (see column a). The cost of a crisis is shown in column (b). Using this as a base, one can then multiply (a) by (b) to obtain the expected benefit per year of increasing the capital ratio by one percentage point. The benefit is stated in column (c) and thus corresponds to the decline in probability of a crisis multiplied by the cost of a crisis.[22]

At the same time, a higher capital ratio entails a cost in that it becomes more expensive for households and companies to borrow from banks, and this cost is stated in column (d). The difference between the expected benefit of a higher capital ratio and the cost of the same, give the social net benefit in column (e).

In Table 9, the cost of a crisis is assumed to be 180 per cent of GDP. Meanwhile, we know from previous sections that an increase in the capital ratio of one percentage point may cause banks to increase their lending rates which in turn may result in a lower GDP level in the long run. Using our estimates from previous sections, the social net benefit of the first increase in the capital level in this example can be calculated as 1.69 per cent of GDP, see Table 9. The social net benefit is positive, that is, the benefit is greater than the cost, in all three cases.

Table 9. Example - Net benefit of increasing capital ratios by 1 percentage point
Probability per year and benefit and cost in per cent of GDP

Increase in equity to total assets	Decline in probability of a crisis (per cent)	Cost of a crisis (per cent of GDP)	Expected benefit (a)×(b) (per cent of GDP)	Cost (per cent of GDP)	Social net benefit (c)-(d) (per cent of GDP)
	(a)	(b)	(c)	(d)	(e)
1 percentage point	1.0	180	1.80	0.11	1.69
An additional percentage point	0.5	180	0.90	0.11	0.79
An additional percentage point	0.1	180	0.18	0.11	0.07

Source: Own calculations

Raising capital ratios reduces the risk of a crisis

The question is then what constitutes an appropriate capital ratio. To calculate this, we seek the highest possible capital ratio at which a further increase in capital ratios still provides a positive social net benefit (e) in Table 9. This is done in several steps.

The first step involves calculating a threshold value, or break-even point, after which it is no longer profitable to raise the capital ratio. The threshold value is calculated by dividing the cost of increased capital ratios (column d in Table 9) by the cost of a crisis (column b).

[22] Note that the benefit is shown in the decline in probability of a banking crisis one year ahead multiplied by the cost of a crisis that is a current value of future costs. This reflects the fact that crises are assumed to result in a permanently lower GDP every time they occur. Let us assume that one could pay a premium to avoid crises for certain for one year. Under the assumption of risk neutrality, it is worth paying the premium as long as it does not exceed the probability of a crisis occurring during the year multiplied by the discounted present value of the social cost of a crisis.

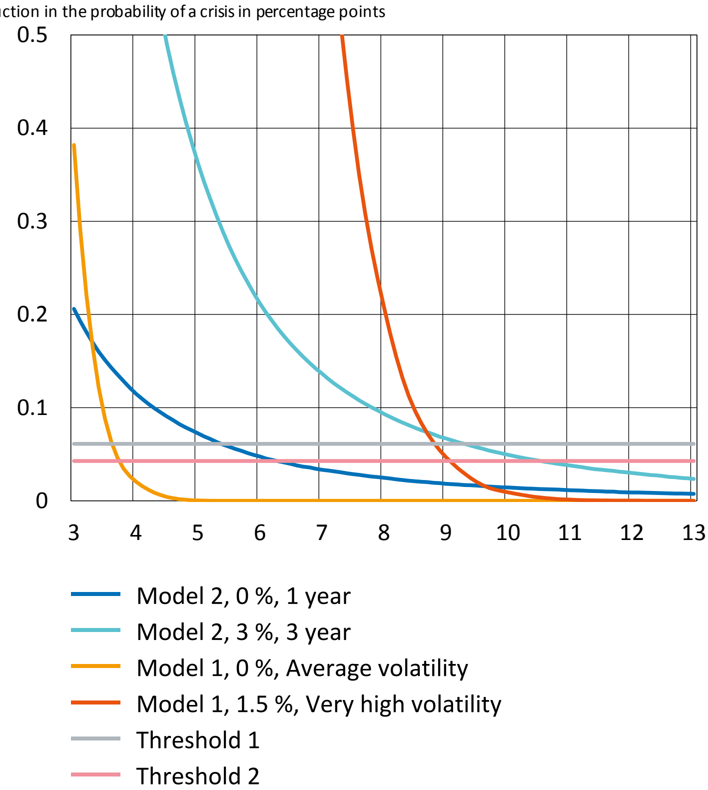
In a second step we can then examine how different capital ratios affect the probability of a crisis (a). As mentioned above, the probability of a crisis declines with each increase in the capital ratio, but the effect becomes smaller the higher the capital ratio we already have. If the positive effect of raising the capital ratio further is less than the threshold value, it is no longer socially beneficial to continue raising the capital ratio. The social benefit will then be lower than the cost and thus there will be no net benefit.

We have calculated a threshold value in a main scenario based on the assessments of the cost of a crisis and the cost of an increased capital ratio of 180 percent and 0.11 percent of GDP respectively, which were reported in earlier sections and are shown in Table 9.[23] We have also estimated the link between an increase in the capital ratio and the probability of a crisis occurring, using Model 1 and Model 2.[24] These values are compared in Chart 6. The different curves show estimates under different assumptions. In Chart 6, the labels 0, 1.5 and 3 percent refer to the critical levels at which a crisis will break out. One year and three years, respectively, refer to the time horizon of the losses based on which the model has been estimated, and Medium, High and Very High refer to the assumption of asset volatility.[25]

The points where the probability curves intersect the threshold values indicate a level at which it is appropriate to raise capital ratios by an additional percentage point, but no more. The appropriate capital ratio for different assumptions, is thus given by the capital level at which the lines intersect plus an additional percentage point.

Chart 6. The effect of higher capital ratios on the probability of a crisis, for different assumptions

Reduction in the probability of a crisis in percentage points



Note. The percentages in the legend refer to different critical equity ratios. 1 year and 3 years refer to historical losses 1 and 3 years ahead respectively.

Source: The Riksbank. See Appendices D and E for a more detailed description

[23] If the cost of a crisis is 180 per cent of GDP and the cost of the banks increasing their lending rates is 0.11 per cent (impact on GDP), the threshold value will be 0.11/1.8, that is, around 0.06 percentage points.

[24] Appendix D and Appendix E contain accounts of 12 different specifications of Models 1 and 2, which are used as a basis for the calculations. Here only a sample is illustrated to show the spread of the results. Our assessment is that all estimated variants are relevant and the purpose of the selection is partly to illustrate the sensitivity of the assumption and capture the extremes given the assumptions made.

[25] In the previous section the relationship is described in terms of the level of probability of a crisis and the banks' capital ratios. Here we describe the same relationship but expressed as how far the probability of a crisis at a given capital ratio will decline when the capital ratio increases by one percentage point.

The Chart also illustrates an alternative threshold value (threshold value 2) which has been calculated on the basis of an alternative scenario that assumes a higher cost of a crisis and a lower cost of higher capital ratios. The cost of a crisis is assumed in this alternative scenario to be 257 per cent of GDP in present value term, which corresponds to the higher estimate for the Swedish 1990s crisis in Boyd et al. (2005). This higher assumption is justified by the Swedish banking sector having grown substantially in relation to GDP in recent decades, having become more interconnected and having increased its dependence on wholesale funding. As explained above, the estimated cost of a crisis is also dependent on the chosen discount rate. If one takes into account current assessments of long run interest rates, there may be justification for a present value calculation of future welfare losses with a lower discount rate. A lower discount rate makes the value of future income greater and thus the welfare loss from crises become greater. In addition, the cost of increased capital ratios is assumed to be half as big in the alternative scenario as in the main scenario. This is justified in part by our cost calculation being based on two different models, one of which does not incorporate the Modigliani-Miller offset. There may thus be a tendency to overestimate the cost. In addition, companies may fund investments in other ways than by borrowing from banks. Both of these factors indicate that the effect on investments and GDP can be less than in the main scenario.

An appropriate capital ratio is in the interval 5-12 per cent

Each declining line in Chart 6 shows how much further one additional percentage point of equity reduces the probability of a crisis estimated with Model 1 and Model 2 for different assumptions regarding volatility, time horizon and critical level. The points where these declining lines intersect the threshold values indicate a level at which it is appropriate to raise capital ratios by an additional percentage point, but no more, for a given set of assumptions. By adding one percentage point to each of the different capital ratios at which the lines intersect we thus arrive at a range of appropriate capital ratios.

All of the intersection points are in an interval of between approximately 4 and 11 per cent capital in relation to total assets. The most cautious estimate thus finds it beneficial to raise by one further percentage point from a capital ratio of 4 per cent to a ratio of 5 per cent, approximately. In other words, all of the estimates indicate that a well-balanced capital ratio is at about 5 per cent or higher. The other estimates imply that it is socially beneficial to raise even at higher ratios. Even with a capital ratio of 11 per cent, it may be socially desirable to raise by a further percentage point to 12 per cent.

All in all, our calculations indicate that an appropriate capital ratio for Swedish banks may be in the interval of about 5-12 per cent of total assets.

Many other studies show similar results

Several recent studies find support for higher capital ratios in line with our results. Firestone et al. (2017) uses a similar approach to the one in this analysis which results in similar capital ratios for banks in the United States. Dagher et al. (2016) find on the basis of panel data from a large number of countries over a long period of time that capital ratios of 8-13 per cent of the banks' total assets would have been sufficient to avoid most of the banking crises that have taken place in these countries since 1970.[26] Examples of other studies that also find that higher capital ratios may be appropriate from society's perspective include Fender and Lewrick (2016), Bair (2015), Calomiris (2013), the Federal Reserve Bank of Minneapolis (2016) and Admati and Hellwig (2013).[27] Other studies find support for lower capital ratios. One of the reasons for this is that they have chosen to assume that the cost of a crisis will be lower using the justification that the new resolution framework can be expected to reduce the cost, see for example Brooke et al. (2015). Another reason why the estimates are lower is that they refer to risk-weighted capital ratios in other countries. As the risk

[26] The definition of avoiding a crisis in Dagher et al. (2016) is in the main scenario that the banks have 1 per cent equity (to total assets) left after loan losses in a given year. In an alternative scenario, they set this safety margin at 3 per cent.

[27] The studies argue for the following ratios: Fender and Lewrick (2016): 4-5%; Bair (2015): 8%; Calomiris (2013): 10%; Federal Reserve Bank of Minneapolis (2016): 15%; Admati and Hellwig (2013): 20-30%.

weights in Sweden are comparatively low, it is difficult to transfer these results to Swedish conditions.

Conclusion

Calculating an appropriate capital ratio involves a great deal of uncertainty. The calculations can be made in many different ways, and whichever way one chooses the results are sensitive to the choice of model and the assumptions made.

With our approach, which largely follows method used in several earlier studies, and with our assumptions, it is socially beneficial to have capital ratios in the interval of 5-12 per cent of a bank's total assets. One cannot rule out the possibility that a well-balanced capital ratio is above or below this interval. Our results indicate higher capital ratios than those in the Riksbank study from 2011, reflecting new data and research, among other things. Our results are in line with several more recent studies.

At present, there is no leverage ratio requirement for Swedish banks. The banks' leverage ratios, measured as equity in relation to total assets, have fallen over time and are now around five per cent. The calculations indicate that it could be socially beneficial to have higher capital ratios than those the major Swedish banks currently have.

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Appendix A - Do higher capital requirements affect lending rates?

Cristina Cella

Introduction

In this memo, we discuss whether raising capital requirements[28] increases the cost of financial intermediation and, if so, how large this effect may be and whether borrowing for firms and households might be negatively affected.

Higher capital requirements make borrowing from banks more costly if both of the following apply:

(i) forcing banks to replace some of their debt financing with equity financing raises their average cost of capital, and
(ii) banks pass this higher cost onto borrowers by increasing margins on loans to firms and households.[29]

In theory, in the absence of frictions, an increase in capital requirements should have no effect on banks' funding costs, and hence on lending rates, in the long run. However, financial frictions exist and a review of international empirical research suggests that raising banks' equity to total assets by one percentage-point results in an increase in lending rates of 16 basis points on average.

To better understand why lending spreads may increase as a result of higher capital requirements, we discuss a number of market frictions of relevance to banks' cost of capital, and we also consider the potential effects that a possible increase in lending rates could have on the overall economy. In particular, we note that adverse effects on investment and GDP will materialise only if firms are unable to offset the higher cost of bank loans. If firms are able to access alternative financing sources, their cost of capital would increase by less than the increase in banks' lending rates, and the effects on the entire economy will be smaller than otherwise implied. In addition, some of the frictions that may contribute to raising banks' funding costs – if they reduce their leverage – are linked to subsidies for debt financing that may distort the allocation of resources in the economy and lead banks to take on too much debt from a social point of view. Keeping these factors in mind, we emphasise the distinction between *private costs* incurred by banks and *social costs* incurred by the economy as a whole when discussing the results.

[28] In this memo, we express capital requirements in terms of equity to total un-weighted assets. In particular, when we talk about an "increase in capital requirements" we refer to banks increasing equity to total assets by one percentage point.

[29] Note that the underlying assumption here is that the larger cost of funding that a bank may experience because of higher capital requirements is passed exclusively to borrowers. In particular, this assumption suggests that, to meet capital requirement while keeping its return on equity unchanged, a bank increases lending rates so that the increase in net income exactly cancels out the increase in funding costs. See King (2010) for a description of the mechanism.

The Modigliani-Miller framework

Whether or not increasing capital requirements – thereby forcing banks to finance themselves with more equity and less debt – affects a bank's overall funding cost is an empirical question.

In theory, the effect on banks' funding costs, and hence on the lending rates, could be zero in the long run. In their seminal paper published in 1958, Modigliani-Miller (hereinafter MM) show that, in a world without frictions, the combination of debt and equity with which a firm chooses to finance its operations is irrelevant to its average cost of capital. In such a frictionless world, reducing leverage[30] does not affect a firm's average cost of capital.

The MM framework recognises that issuing equity may be more expensive than financing with debt, but points to an offsetting benefit of additional equity. First, when leverage is reduced, the firm's outstanding debt becomes less risky, since there is more equity to absorb losses. Second, the probability of the firm's defaulting decreases and the volatility of the return on equity falls. This should make a firm's equity less costly. In a perfect world, the firm's weighted average cost of capital (WACC) remains unchanged.[31]

For financial institutions such as banks, the MM irrelevance theorem implies that, in a world without frictions, better capitalised banks can issue less risky – and hence cheaper – equity while maintaining the same portfolio of loans.[32] In that case, increasing a bank's capital requirements would not affect either its lending rates or its lending volumes. In practice though, banks face some specific frictions that make capital structure relevant for their cost of capital. Broadly speaking, one could put these frictions into two broad categories:

a. government intervention,
b. market frictions.

In the following, we give a brief description of each category and illustrate specific frictions that might be of particular relevance to a bank's cost of capital.

Government intervention

If the government intervenes with tax breaks or subsidies that make financing with debt more attractive that financing with equity, this distortion will affect the way companies may finance

[30] Here we refer to leverage as the proportion of debt (D) over equity (E): debt-to-equity ratio (D/E). Keeping debt constant, leverage then decreases as the equity base increases. Note, though, that Basel III uses a different definition of leverage: Equity to Assets (E/D+E). Considering the Basel III definition of leverage, keeping assets constant, leverage decreases as the leverage ratio increases.

[31] Modigliani and Miller proposition I states that the sum of the market value of equity (E) and the market value of debt (D) is equal to the market value of the unlevered assets (U):

$$E + D = U \qquad (1)$$

This equation suggests that, by holding a portfolio of the firm's equity and debt, the investor is able to replicate the cash flows from holding the unlevered security. Because the return of a portfolio is calculated as the weighted average returns of the securities it contains, equality (1) implies that:

$$\frac{E}{E+D} Re + \frac{D}{E+D} Rd = Ru \qquad (2)$$

Where Re is the cost of (levered) equity, Rd is the cost of debt and Ru is the cost of unlevered equity or WACC (weighted average cost of capital). From equation (2), it follows that:

$$Re = Ru + \frac{D}{E}(Ru - Rd) \qquad (3)$$

A firm's cost of equity depends on the firm's operating risk (the riskiness of the cash flows of the assets absent any leverage) and the firm's financial risk, which depends on the firms' level of leverage. Modigliani and Miller proposition II states that the cost of levered equity increases with the firm's market value of the debt-to-equity ratio (D/E).

[32] See Admati, DeMarzo, Hellwig and Pfleiderer (2011) for an extended discussion.

their operations. The same type of distortion happens if the government offers (unpriced) guarantees of liabilities.

Frictions due to government intervention affect a bank's capital structure decisions in different ways. To begin with, in many countries, interest payments on debt are deducted against a firm's corporate income while dividends to shareholder are not. Hence, using debt gives rise to a valuable tax shield. So banks, like any other company, maximise the value of their tax shield by increasing leverage. If leverage is reduced, some of these benefits are lost, and this can affect (albeit marginally) a bank's cost of capital.

To give a concrete example, assume that new equity replaces long-term debt in a bank's capital structure, and that the only effect on the bank's cost of capital comes from the lost tax shield on debt. Let us assume that, in Sweden, the average coupon on the long-term debt is 5 per cent and the corporate tax rate is 22 percent. If equity increases one percentage point, the lost tax shield will be given by the coupon times the tax rate (0.05×0.22) = 0.011 per cent, or 1.1 basis points. This implies that, keeping assets constant, if banks had to issue one extra percentage point of equity, their cost of capital (WACC) could increase by about 1.1 bps.[33]

It is important to notice that a favorable tax treatment of debt over equity also creates potential "clientele effects" (Stiglitz (1973) and Miller (1977), among others). The clientele effect hypothesises that the common stocks of highly levered firms will be held by investors with low personal tax rates, while the shares of firms with little or no leverage will be held by individuals with high personal tax rates. Thus, in order to attract a certain type of investor, a company may not choose the capital structure that is best to support its operations, but that which reflects the specific preferences of its "preferred set" of investors. While the cost of this friction is difficult to quantify numerically, the existence of such a problem highlights the many ways in which government regulation can distort how banks finance their operations.

Other types of government intervention that could substantially affect banks' preference for high leverage are implicit (too-big-to-fail type) and explicit (deposit) guarantees.[34] Banks' shareholders benefit from these guarantees because they make the claim of debt holders and depositors less risky on average[35] and are thus less costly from the financing perspective of the bank. Replacing debt with equity might then result in a higher funding cost.

Importantly, the larger cost that banks may incur because of forgone guarantees is not a social cost but a private one. The existence of guarantees might encourage banks to take excessive leverage and/or hold more illiquid assets (Diamon and Rajan (2012)). This behaviour makes the portfolios of banks riskier, and shifts risk from the banks' equity holders to the banks' depositors and debt holders. Therefore, guarantees provide shareholders with a private benefit, but have no clear social benefit: a) in normal times, guarantees allow banks to fund themselves with cheaper-than-otherwise debt, thus giving them an incentive to lever up; and b) during a financial crisis, guarantees represent a transfer from taxpayers to shareholders. If guarantees generate inefficient behaviour, reducing their use might actually generate social benefits.

Government guarantees, or better, the existence of financial contracts used to overcome the lack of them, also create another friction known as the debt convenience premium. Banks not only raise money from retail depositors, but also largely rely on wholesale debt raised from institutional investors (such as sovereign wealth funds and mutual funds) and cash-rich companies that are not protected by deposit guarantees. To offer non-retail investors a safety

[33] These calculations are in line with the results of Kashyap, Stein and Hanson (2011) who also document a small increase in the representative US bank's cost of capital due to the lost tax shield.
[34] See Elliott (2009) and Miles et al. (2013) for an extended discussion of this topic.
[35] This is because debt holders and depositors are more likely to recover part if not all of their claims in bad states of the word.

net similar to that enjoyed by retail investors, banks use structured financial instruments that make their investment essentially default-risk free.

When institutional investors provide funds to a bank, they are paid an interest rate and receive collateral through an instrument similar to a repo agreement. The investor buys (at a discounted price) the collateral from the bank and the bank agrees to repurchase the same asset at a later date (usually the day after) at a higher price. If the bank defaults, the investor keeps the collateral and is therefore insured against default risk. This system allows institutional investors (and more specifically money market funds) to have a flexible and safe investment that not only produces some interest but also allows the funds to access their cash almost on demand.[36] Given this convenience, institutions are then willing to accept a lower interest rate from banks, and short-term wholesale debt has therefore become a highly attractive form of funding for banks. In other words, some wholesale short-term debt may carry a valuable money-like premium.[37]

Understanding the money-like premium is important because, when studying the impact of capital requirements, most authors assume that equity replaces long-term debt (which is more expensive than short-term debt on average). However, if banks are heavily funded with short-term wholesale debt, it is reasonable to assume that they may need to replace some of this debt with equity and lose the money-like premium they make. Nevertheless, this kind of cost might be quite small. For a one percentage-point increase in capital requirements, Kashyap, Stein and Hanson (2011) report that the lost money-like premium would make funding for the average bank in the US *at most* 1 bp more expensive.

Market frictions

In the perfect world postulated by Modigliani-Miller, markets are completely frictionless so firms have easy access to financing and can freely choose their capital structure. In reality, when a company tries to raise more financing, this could be quite expensive. Some important frictions in this context are related to asymmetric information issues and market competition.

Because of asymmetric information, financiers may be unable to correctly price the assets of a company and they may require higher compensation for risk than is otherwise necessary (Ross (1977) and Leland and Pyle (1977)). However, companies might not accept the lower price investors are willing to pay and may try to issue equity when the discount can be minimised (Myers and Majluf, 1984). Investors though anticipate that managers may issue equity when the stock is likely to be overpriced and react negatively to announcements of equity issues (i.e. the company stock price declines upon announcement) deterring managers from issuing equity in the first place. Managers may then choose to finance with retained earnings first, debt second and new equity in the final instance – following the "pecking order theorem" of Myers (1984).

Since banks have very opaque balance sheets, they could be more adversely affected by asymmetric information issues when raising new equity.[38] On the other hand, while asymmetric information issues might be particularly significant when a single bank tries to raise equity, if *all* banks need to issue new equity to meet the regulatory minimum capital requirement, asymmetric information may affect them less severely.

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[36] Gordon and Metrick (2010) provide a full description of the "securitise-banking" system and the use of repo agreements.
[37] Gorton (2010), Gorton and Metrick (2012) and Stein (2012) are among the first to discuss this specific friction.
[38] See Bolton and Freixas (2006) for more details about how asymmetric information may affect a bank's net worth.

Another important friction for banks is the degree of competition in the market. Market competition, however, may not directly affect a bank's cost of capital, but rather its ability to pass an increase in this cost on to its clients.

The main competitive advantage of banks is their ability to access cheap funding. If, in a competitive environment, banks' funding costs increase, some banks may not be able to compete and could be eventually run out of business. This would make the market more concentrated and could have adverse consequences for borrowers, since banks may increase interest rates more easily.

In already concentrated markets, increasing capital requirements might not reshape the industry structure, but might indeed affect lending rates: when unable to deleverage (assets are kept constant) but forced to raise equity, banks may charge higher interest rates and/or fees to their customers in order to compensate for the decrease in investors' return on equity (ROE) and keep their target ROE.[39,40]

With four big banks (Nordea, SEB, SHB and Swedbank) that dominate the industry with about 80 per cent of market share, Sweden has a very concentrated banking sector. Therefore, while the risk of further concentration in the local market may not be real, banks may indeed transfer all of the extra costs incurred by higher capital requirements directly onto borrowers. Still, banks do not necessarily have to increase lending rates to offset the increase in their funding cost. The ability of banks to charge more for loans is not only conditional on the degree of competition in the banking sector; it also depends on the availability of credit through private capital markets, and the elasticity of loan demand. King (2010) suggests that, before banks modify lending rates, they could (i) reduce operating expenses, (ii) increase non-interest sources of income, (iii) redirect activity towards more profitable lines of business, or (iv) absorb the higher costs and reduce ROE. These alternatives suggest that, also in a highly concentrated industry, lending rates need not to increase because of higher capital requirements.

The short discussion above very briefly summarises the tension between the benefits and costs of debt and equity financing, and suggests that frictions make a firm capital structure relevant to its cost of capital. Nonetheless, many studies document that, when companies substitute debt financing with equity financing, their overall cost of capital increases less than what it would have done in the absence of any mitigating effects, due to lower leverage and less risky equity. This effect is commonly referred to as the "Modigliani-Miller offset" and it is well-documented also for the banking sector, as Table 1 shows.[41]

The studies in Table 1 suggest that, once equity is raised, the actual cost of capital of a bank might not increase by as much as some critics suggest:[42] Consistent with the MM offset, replacing debt with equity makes a bank less risky (i.e. the bank's equity beta decreases[43]) and this benefit offsets in part the cost implied by potential frictions. Lately, though, some authors

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[39] Elliot (2009) discusses why banks may intend to keep their target ROE and Kashyap, Stein, and Hanson (2011) discuss the issue of competition in the banking sector.

[40] Kisin and Mandela (2016) suggest that banks may perceive equity to be arbitrarily costly. Theoretically, the costs could be substantial if the fragile capital structure is necessary for bank operation (Calomiris and Kahn (1991) and Diamond and Rajan (2001)). Admati, DeMarzo, Hellwig, and Pfleiderer (2011) and Admati and Hellwig (2013) suggest opposite arguments. Equity may also increase bank value by improving incentives (e.g., Holmstrom and Tirole (1997); Allen, Carletti, and Marquez (2009); Mehran and Thakor (2011)).

[41] To give an idea of the MM offset, we will refer to the example illustrated by Miles, Yang and Marcheggiano (2013). On page 13 of their paper, they show that, in the absence of any Modigliani ad Miller offset, a 15 percentage point increase in capital to un-weighted assets would increase the cost of capital of the average bank in the UK by approximately 33 bps. However, using their fixed effects estimate in Table 1, they show that the actual increase in the average bank cost of capital is only 18 bps, not 33 bps; in other words the actual increase is 45 per cent lower than in the case without MM offset.

[42] See for instance the study that the Institute of International Finance (IIF) published in 2010.

[43] Kashyap, Stein, and Hanson (2010) show that in a panel of large banks, those with less leverage have significantly lower values of both beta and stock-return volatility.

have questioned the existence of the MM offset, suggesting that a different issue may be particularly important to consider in this contest: the low-beta anomaly.

Table 1. Evidence of the Modigliani-Miller offset.

(1)	(2)	(3)	(4)
Paper	**Country**	**Data Period**	**MM Offset**
ECB (2011)	54 Global Banks	1995-2011	41%-73%
Junge and Kugler (2013)	Switzerland	1999-2010	64%
Miles et al. (2013)	UK	1997-2010	45%-90%
Shin (2014)	105 Advanced Economy Banks	1994-2012	46%
Toader (2015)	European Banks	1997-2011	42%
Bank of England (2015)	UK	1997-2014	53%
Clark et al (2015)	US	1996-2012	43%-100%

Column (1) records the title of the papers, column (2) describes the countries involved in the study, column (3) reports the time period used in the study, and column (4) shows the Modigliani and Miller (MM) offset documented by the paper.

The standard Capital Asset Pricing Model (CAPM) postulates that investors should be compensated for taking systematic risk (beta). However, Ang, Hodrick, Xing and Zhang (2006) document that stocks with lower beta have historically earned higher returns than stock with higher beta. The existence of this anomaly suggests that, all else equal, companies with low risk may have to pay more, not less, for raising extra equity financing, and thus end up with a higher cost of capital (Baker and Wurgler, 2014). Then, even in a perfect world, the Modigliani-Miller capital structure irrelevance theorem fails (Baker and Wurgler, 2015). Baker and Wurgler (2015) estimate that, because of the low-beta anomaly alone, the weighted average cost of capital of the average US bank may increase 8.5 bps after a one percentage-point increase in capital requirements.

The discussion above highlights that, because of frictions, after increasing equity to total un-weighted assets by an additional percentage point, banks might experience an increase in their cost of capital and they may pass this increase to borrowers by increasing lending rates. So, the next question is: how much does a one percentage-point increase in equity to total assets affect lending rates? This issue is discussed in the following section.

Existing literature on lending rates

The literature on how capital requirements affect lending rates has evolved quite substantially from initial attempts in the aftermath of the financial crisis. Data availability and more sophisticated estimation frameworks have contributed to more direct and better developed studies.

Table 2 summarises some of the most cited papers in this fairly extensive literature. For the sake of simplicity, the studies have been divided into those that explicitly employ the MM framework (row (1)–(7) of Table 2), and those that use alternative methodologies (row (8)–(13) of Table 2).[44] All of the results have been harmonised so that we always report the change in

[44] The papers that use alternative methodologies mostly employ structural models, including general or partial equilibrium models, and accounting equations. Just to give an intuition, structural econometric models use economic theory to develop mathematical statements about how a set of observable “endogenous” variables (y) are related to another set of observable “explanatory” variables (x) and unobservable variables (z). Methods using accounting identities start by the basic principle that total assets must equal total liabilities and use stylised balance sheets and calibrations based on a representative bank.

lending rates associated with a one percentage-point increase in equity to total assets, also when the original study investigates capital to risk-weighted-assets (RWA) type of requirements.[45]

The studies that use the MM framework proceed in two steps: (a) they study how the cost of capital of a bank is affected by the change in capital requirements; and (b) they study how much of the change in the bank's cost of capital is passed on to clients, and thus how much more expensive it becomes for (corporate) customers to finance their investments. As supported by existing empirical literature (De Bondt (2005), Harimohan, McLeay and Young (2016) and Mojon (2000)), most studies assume that the increase in funding costs is fully transferred onto borrowers.[46]

Table 2. Empirical evidence of the impact of a one percentage-point increase in capital requirements on lending rates.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Study	Year	Country	Time Period	Type of Study	Methodology	MM Offset	Δ Lending Rates (bps)
	A. Papers using the MM framework:							
(1)	BCBS*	2010	13 OECD countries	1993-2007		Calibration		26
(2)	Junge and Kugler	2013	Switzerland	1999-2010		Calibration	64%	0.70
(3)	Miles, Yang and Marcheggiano	2013	UK	1997-2010		Calibration	45%	1.20
(4)	Bank of England	2015	UK	1997-2014		Calibration	53%	25
(5)	Elliot	2009	US			Calibration	Implicit	20
(6)	Kashyap, Stein and Hanson	2011	US	1976-2008		Calibration	Implicit	3.50
(7)	Baker and Wurgler	2013	US	1971-2011		Empirical + Calibration	Implicit	8.50
							Average	**12.13**
	B. Papers NOT using the MM framework:							
(8)	Cosimano and Hakura	2011	Global	2001-2009	Structural Model	Empirical		12
(9)	King*	2010	13 OECD countries	1993-2007	Accounting Identities	Calibration		30
(10)	Slovik and Cournede*	2011	3 OECD countries	2004-2006	Accounting Identities	Calibration		32
(11)	De Resende, Dib and Perevalov*	2010	Canada		General Equilibrium Model	Calibration		2.50
(12)	Corbae and D'Erasmo*	2014	US		Structural Model	Calibration		50
(13)	Kisin and Manela*	2016	US	2002-2007	Partial Equilibrium Model	Empirical		0.30
							Average	**21.13**
							Overall Average	**16.28**

Column (1) records the title of the papers, column (2) reports the year of the last available version, column (3) describes the countries involved in the study, column (4) reports the time period used in the study, column (5) briefly summarises the type of study, column (6) describes whether the study was conducted using an empirical, regression-based, approach or a calibration approach. Column (7) reports the estimated MM offset and column (8) reports the effect of a one percentage-point increase in capital to un-weighted total assets on lending rates (in basis points). * Indicates papers that originally investigate the effect of a one percentage-point increase in capital to risk-weighted-assets (RWA). To harmonize the results, RWA is assumed to be 50 per cent on average of total un-weighted assets.

Overall, the main takeaway of Table 2 is that a one percentage-point increase in capital requirements has a relatively small impact on funding costs and therefore on lending rates (about 16 bps on average), and more recent evidence (see for instance Kisin and Manela (2016)) finds smaller effects. These results though should be interpreted with caution.

To begin with, banks face different institutional settings in each country and thus most of the results depend on the banking sector's country-specific characteristics. Another potential problem is that changes in capital requirements are studied in isolation from other policy changes. The results obtained might therefore only capture an incomplete part of the actual effect. For instance, if several pieces of regulation change together, the collective effect of these changes could result in larger (or smaller) estimates than those reported in the aforementioned studies.

45 To harmonise all the papers, we translate all of the results assuming that on average RWA is 50 per cent of total assets. This is currently the best we can do because of the lack of information on the actual proportion of risk-weighted-assets (RWA) to total assets in countries around the world. Data was requested from BIS but our request could not be met because of privacy issues.

46 Miles et al. (2013) and Junge and Kugler (2013) are the only two papers that deviate from this assumption in their main conclusion. However, to better compare the results across all papers, in Table 2 their results are adjusted so that the pass-through is 100. Note that this assumption makes the magnitude of their effects larger than otherwise reported in their papers.

It is also important to note that most of the studies use highly simplified assumptions: banks have only loans in their portfolios, all equity is common equity, equity replaces long-term debt, the tax rate is constant (this affects the tax value of the debt tax shield) and banks are not able to change their assets. Changing one or more of these assumptions may substantially affect the final estimates. Lastly, studies that use calibrations are very sensitive to the way inputs are obtained.

To conclude, it is important to keep in mind that, when interpreting the results collected in this very brief survey, the borrowers must be considered too. While banks may be willing to charge higher lending rates to their customers, corporate borrowers may look for credit elsewhere (less regulated institutions or shadow banks may capture part of the market of more regulated banks), and may even choose to adjust their own capital structures. Faced with more market competition, banks may then reconsider the decision to pass a large part of their increased funding costs onto their customers. Therefore again, the structure of the banking and financial system plays a crucial role when assessing the real economic consequence of changes in capital requirements.

Existing evidence on lending volumes

Another aspect to consider to fully assess the impact that changes in capital requirements may have on the real economy, is how they affect lending volumes in the steady state.

While banks could react to higher capital requirements by increasing lending rates, they could also choose to keep their lending rates at the same level and instead reduce the amount of credit to the economy to minimize the cost of monitoring borrowers in order to avoid losses. They might of course concurrently increase lending rates and reduce lending volume. While a reduction in the supply of credit to households and corporates may have strong consequences for the real economy, one should not forget that a demand side effect is also possible. In well-functioning markets, keeping investment opportunity constant, if banks increase lending rates as a consequence of higher capital requirements, borrowers might look elsewhere for credit. This latter effect would create an observational equivalence: while it might seem that banks have reduced credit to the economy, in fact, it is customers that are borrowing less from banks to finance their consumption and businesses. If this is the case, changes in capital requirements should be have quite limited effects on the real economy in the long run.

Also if unable to distinguish between a demand-side effect and a supply-side effect, many authors have been studying the consequences that changes in capital requirements could have on lending volumes. Since the aim of this review is to focus on lending rates, we will only briefly review two (more recent) papers that contribute to the literature on how changes in capital requirements might affect lending volumes. We refer readers to the BIS report no. 30 published in March 2016 for a richer summary.

Mendicino, Nikolov, Suarez and Supera (2015) show results not only on lending rates but also on volumes. The authors incorporate the banking system in a standard DSGE model and consider a framework in which banks lend to both households and corporates and where all borrowers may default on their lenders due to idiosyncratic and aggregate shocks. They calibrate their model using data from the euro zone over the period 1999–2013. While the original paper does not directly report results for lending rates and lending volumes, the BIS paper no. 30, published in March 2016, reports authors' calculations (see Table 1 and Table 2 in the report). In the BIS report, the authors suggest that, in the long run, an increase of one percentage-point in the ratio of capital to risk-weighted (un-weighted assets[47]) is associated

[47] RWA=50 per cent*Total Assets

with an increase in lending rates of 2.8 (5.6) bps for households' mortgages and 4.9 (9.8) bps for corporate loans. Moreover, credit growth falls by about 0.15 per cent (0.3 per cent) for households and 0.43 per cent (0.86 per cent) for corporates. Small effects are also documented by Noss and Toffano (2014) who, using data on UK banks over the period 1986–2010, find that an increase of 15 bps in un-weighted capital requirements is associated with a median reduction of around 1.4 per cent in the level of lending after 16 quarters. If we consider an increase of equity to total un-weighted assets of just one percentage-point, the median effect on lending volumes amounts to 0.093 per cent in the level of lending after 16 quarters.

The modest effects found by Mendicino et al. (2015) and Noss and Toffano (2014) are also confirmed by a large body of literature. These studies, like those on lending rates, conclude that the effect of capital regulation on lending volumes should be quite modest in the long run.

Conclusion

In the above, we have taken the Modigliani-Miller theorem as a starting point for a discussion of how banks' funding costs may be affected by higher capital requirements. The theorem predicts that, in the absence of taxes and other frictions, banks' funding costs may not be affected at all in the long run. In practice, there are relevant frictions to consider that may cause banks' funding costs to increase somewhat as a result of higher capital requirements. Yet, existing research also finds support for the existence of some degree of Modigliani-Miller offset. Overall, the studies reviewed in this memo show that raising banks' equity to total un-weighted assets by one percentage-point may result in an increase in lending rates that ranges between 0 and 50 bps, 16 bps on average.

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Appendix B - The impact of higher capital requirements on GDP

Anna Grodecka

Introduction

Higher capital requirements, while reducing the probability of a crisis, may also be costly for society. More specifically, they may increase banks' funding costs, and banks may respond by raising lending rates.[48] This could have a negative impact on the investment of companies that finance their production with bank loans, and on the spending of households that use bank credit to finance their consumption, potentially resulting in a lower GDP level.

There is uncertainty about how much capital requirements would actually raise the cost of capital in the economy. The extent to which banks' funding costs could increase due to higher capital requirements and are passed on to banks' clients depend on country- and regulation-specific factors and the degree of the Modigliani-Miller offset (for a more detailed discussion, see Appendix A). The Modigliani-Miller theorem states that funding costs of a bank should not depend on the mix of equity and debt financing (Modigliani and Miller, 1958).[49] With higher equity, a bank becomes safer, and as such, the required return on equity should fall, making it relatively less expensive. However, due to various frictions including, but not limited to, tax subsidies for debt financing and explicit and implicit government guarantees, this Modigliani-Miller offset does not fully materialize in reality. Thus, if we require banks to hold more equity, their funding costs will likely increase. However, it should be noted that, in order for higher capital requirements to reduce corporate investment, the Modigliani-Miller theorem has to fail twice, both at the bank level and the company level.

We evaluate the long-run GDP effect of increased capital requirements using two general equilibrium models with different characteristics. These models capture feedback effects between different sectors in the economy. We focus on the impact on GDP once the economy has settled into a new equilibrium (steady state), rather than transitory effects.

The first model contains banks and a capital requirement that allows us to perform the analysis in one step (Iacoviello, 2015). The second model requires two steps: first, an estimation of the effect on banks' lending rates, for which we rely on the estimates from Appendix A. Second, we evaluate the effect of such an increase in lending spreads in the Riksbank's macroeconomic model, RAMSES.[50] Iacoviello (2015) is particularly well-suited to our policy experiment because, unlike many DSGE models, it contains a capital requirement for banks. A benefit of using RAMSES is that the model is particularly apt for the Swedish economy.

Both approaches generate similar results. Our analysis suggests that a 1 percentage-point increase in the equity to total assets ratio may lower the long-run GDP level by about 0.09–0.13 per cent, depending on the model used.[51]

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[48] See Appendix A "Do higher capital requirements affect lending rates?" In this Appendix, we use the terms lending rates and lending spreads interchangeably. We refer to the lending spread as to the difference between lending rates and deposit rates. If capital requirements do not have an impact on the deposit rate (as in the models discussed in this Appendix), the change in the lending spread will be entirely due to the change in lending rates.

[49] Note that the Modigliani-Miller theorem refers to *having* equity and not *raising* new equity. It might be that raising new equity may increase bank funding costs temporarily, but not permanently, if no further frictions occur. See the discussion in Miller (1995).

[50] RAMSES is a DSGE model used at the Riksbank to produce a macroeconomic forecast, alternative scenarios, and for monetary policy analysis. See http://www.riksbank.se/sv/Press-och-publicerat/Publicerat-fran-Riksbanken/Ovriga-rapporter/Occasional-Paper-Series/2013/No-12-Ramses-II--Model-Description/.

[51] These estimates do not change with the starting capital ratio, or change very little.

Different ways of calculating the impact of capital regulation on GDP

Our analysis compares results from different methods. Specifically, we use a one-step and a two-step approach for Sweden and we compare our results with estimates for other countries that have mainly been estimated using a two-step approach. Hence, the results that we discuss belong to three categories, with the last one mainly used for robustness:

1. Steady-state comparison in the Iacoviello (2015) model	One-step
2. Long-run effects of a higher lending spread in RAMSES model	Two-step
3. Empirical and semi-structural estimates of the relationship between lending spreads and GDP for other countries	Two-step

It is not a priori clear which of these methods is superior. Making the calculations in one step puts a lot of faith into one specific model, while spreading the analysis over multiple steps introduces uncertainty at each step of the analysis. Given this uncertainty, we find it suitable to use both (1) and (2) in our analysis for Sweden, and relate the magnitude of that estimate to (3).

Table 1 summarises the results from all three approaches. The remainder of this Appendix discusses the calculations in more detail.

Table 1. Comparison of the results obtained with different approaches

Method/model	Experiment	Change in GDP	Change in lending volume	Change in lending spreads	Change in investment
One-step analysis					
Iacoviello (2015)	permanent 1 p.p. increase in NRWCR[52]	-0.13%	-1.6% Firms: -1.5% Hhs: -1.9%	+46 bp	-0.36%
Two-step analysis					
RAMSES	permanent 16.3 bp increase in lend. rates[53]	-0.09%	-	+16 bp	-0.27%
Empirical and semi-structural estimates for other countries					
Minneapolis Plan (2016)	permanent 10 bp increase in lend. rates	-0.1%	-	-	-
Bank of England (2015)	permanent 10 bp increase in lend. rates	-0.05%	-	-	-
Locarno (2011)	temporary persistent 12 bp increase in lend. rates	[-0.03%, -0.39%]	-	-	-
	permanent 1 p.p. increase in RWCR[54]	-0.18%	-	-	-
Gambacorta (2011)	permanent 2 p.p. increase in RWCR	-0.19%	-0.36%	+5 bp	-

[52] NRWCR stands for non-risk-weighted capital ratio.
[53] The experiment in RAMSES is designed to engineer a 1 p.p. increase in the equity to total assets ratio.
[54] RWCR stands for risk-weighted capital ratio.

Analysis using the Iacoviello (2015) model

The model of Iacoviello (2015) allows us to assess the GDP effects of increased capital requirements in one step, since it features banks facing capital requirements set by a regulator.[55] Banks in the model serve as financial intermediaries, collecting deposits from household-savers and extending loans to entrepreneurs and households that borrow against housing collateral. The capital ratio in the model is defined as the inverse of leverage, in other words, it refers to capital to total assets. The model does not feature risk weights.

The mechanism that ultimately leads to a lower GDP level in the model as a result of an increased capital ratio is best explained in terms of the balance sheet channel. To meet the target of a higher capital requirement, banks can either adjust the asset side of their balance sheet (by deleveraging, thus reducing lending) or the liability side (by raising more capital). If they decide to raise capital, their funding costs increase (in a world with frictions, the Modigliani-Miller theorem does not hold and thus equity is more expensive than debt) and they will pass these higher costs onto their customers, i.e. companies and households, in the form of increased lending rates. In the model, banks adjust both sides of their balance sheet to meet higher capital requirements. As demonstrated in Table 1, they reduce the lending and increase the lending rates, which makes the investment by companies, as well as consumption smoothing and financing by households more difficult. As a result, GDP falls. Note that to the extent that a Modigliani-Miller offset would actually occur, the model we are using will overstate the negative effect on GDP. Analogously, to the extent that companies can use financing sources other than banks, our estimate should be seen as the upper bound on the drop in GDP.

The original model has been calibrated to the US data. We change the calibration to match some aspects of the Swedish data, in particular the ratio of household indebtedness and corporate loans to GDP, the required return on bank equity, and the LTV ratio for mortgages.[56] The steady-state capital ratio is set at 5 per cent and in our experiment, we look at the effects of a 1 percentage-point increase in the capital ratio, from 5 per cent to 6 per cent. As presented in Table 1, GDP decreases by 0.13 per cent. This effect takes into account increased lending rates and a fall in lending to both the corporate and the household sector. Given high levels of household indebtedness in Sweden, the latter effect is important to account for since it points to a channel whereby capital requirements may reduce the cost of a financial crisis, by making households' – not just banks' – balance sheets more resilient (if we believe that there may be too much debt in the economy, which could lead to debt overhang effects).

Comparison with the macroeconomic model used in Sveriges Riksbank (2011)

In 2011, the Riksbank published a study (Sveriges Riksbank, 2011) assessing the real economy costs of higher capital requirements using another DSGE model with banking, developed by Meh and Moran (2010). In our view, several features of the Meh and Moran (2010) model used in the Riksbank (2011) make it less apt for our analysis. In contrast to Iacoviello (2015), in Meh and Moran (2010) the capital requirement is not set by the regulator, but arises endogenously as a result of a moral hazard problem between banks and household-depositors.[57] In practice, this endogenously arising capital requirement means that the capital ratio in Meh and Moran (2010) is a function of other model parameters, and is not one fixed number that can be changed when the experiment of increased capital requirements is conducted.

The endogenous capital level in Meh and Moran (2010) is interesting from a research perspective but arguably makes it less appropriate for evaluating capital requirements from a policy perspective. The reason is that in this model, it is possible to arrive at a capital ratio that is 1 percentage-point higher in multiple ways, by different combinations of parameters

[55] We use the extended model presented in the paper to address our question. Unlike the basic model that features only corporate borrowing, the extended model features both corporate and household borrowing.

[56] In our steady state, mortgage debt to GDP is at 52 per cent, corporate loans to GDP at 117 per cent, ROE at about 12.5 per cent, LTV ratio for mortgages is set at 85 per cent. We match these moments by adjusting the discount factors of economic agents in the model, changing the LTV ratios for households and companies, as well as the capital ratio.

[57] Ensuring investment in good projects involves monitoring costs. Because households cannot observe the extent to which the banks actually monitor, they require the banks to also invest their own funds in the lending operations. This gives the banks "skin in the game", ensuring that they monitor the companies.

influencing the endogenous capital ratio in equilibrium. This can undermine the robustness of the results. Moreover, it seems that reality is more closely aligned with the Iacoviello (2015) model, as banks often have to be forced to hold more capital. The effects on GDP of an experiment in which the parameters are changed to ensure that the economy optimally arrives at a particular capital ratio (as in the Meh and Moran, 2010, model), are likely to be very different from an experiment in which the banks are forced to hold more capital (as in the Iacoviello, 2015, model).

The more recent modelling approach of Iacoviello (2015), which was not available at the time of the Riksbank 2011 analysis, offers a more realistic description of the regulatory framework, as well as a unique and non-disputable way to arrive at higher capital requirements providing for a more transparent analysis. Moreover, while the Meh and Moran (2010) model is silent on household borrowing, the Iacoviello (2015) framework gives mortgage lending an important role. In the face of rising household indebtedness linked to increasing housing prices in Sweden, this channel of bank lending should not be ignored and hence, we opt for using Iacoviello (2015) as our benchmark.

We also compare our estimates to results of similar studies conducted for other countries. Angelini and Gerali (2012) conduct an experiment similar to ours, based on a Gerali, Neri, Sessa and Signoretti (2010) framework estimated for the euro area. Angelini and Gerali (2012) estimate the long-run GDP effect of a 1 percentage-point increase in the risk-weighted capital ratio to range from a minimum of 0 per cent to a maximum of -0.36 per cent, which could potentially imply much higher costs than those reported in this study and in Sveriges Riksbank (2011).

Analysis using RAMSES

The models used to evaluate GDP effects of higher capital requirements in the two-step approach do not have a banking sector or capital requirements incorporated, but they still allow for an examination of the effects of higher lending rates on GDP. A necessary input to this analysis is the lending rate increase whose effects one wants to evaluate. In Appendix A, we summarise a range of studies that estimate the effect of increased capital requirements on lending rates for other countries. We use the average of the estimates found in these studies as input to the further general equilibrium analysis. Comparing different estimates, we find that a 1 percentage-point increase in the capital ratio (non-risk-weighted) on average leads to an increase in lending rates of 16 bps (see Table 2 in Appendix A "Do higher capital requirements affect lending rates?"). This is a lower estimate than that obtained from the Iacoviello (2015) model. It may be due to the fact that the computed average relies both on studies using the Modigliani-Miller framework, and studies not using the Modigliani-Miller framework. Depending on the assumed Modigliani-Miller offset (absent in Iacoviello, 2015), the increase in lending rates due to higher capital requirements differs. Interestingly, despite the differences in the lending rate, both models suggest a similar GDP response, which emphasises the need to use more than one model to ensure the robustness of our results.

RAMSES is a general equilibrium model estimated on Swedish data used at the Riksbank for the purpose of forecasting and monetary policy analysis.[58] Lending spreads in the model are endogenous and are a function of entrepreneurial net wealth amongst other variables. When entrepreneurs have less of their own funds to invest, the lending spreads increase, which raises their cost of investment. In the long run this reduces the capital stock and pushes GDP down.

RAMSES has been used as input for the analysis reported in the Monetary Policy Report from July 2014, that assesses the effects of stricter capital requirements on the economy (Sveriges Riksbank, 2014). Given that lending spreads arise in the model endogenously, in the steady state of the model, the spread is not a fixed parameter, but a function of other model parameters, similar to the capital ratio in the Meh and Moran (2010) model. Changing the

[58] For a description of RAMSES, see Adolfson et al (2013). In the model the repo rate is set according to a simple monetary policy rule in which the repo rate depends on the deviation in inflation from 2 per cent and on resource utilisation, measured as the difference between actual hours worked and potential hours worked.

steady-state lending spread thus requires a judgemental decision and can be done in many different ways. That is why, in our experiment, instead of comparing the steady-state values, we choose to look at the long-run dynamic responses of the log-linearised model to a shock that permanently pushes up the lending spreads.[59] An exogenous shock that drives up the lending spreads by 16 bps leads in RAMSES to a decline in GDP of around 0.09 per cent in the long-run equilibrium, as reported in Table 1.

Empirical and semi-structural estimates for other countries

Apart from conducting the experiments with the models adapted to the Swedish economy, we look at estimates that were made for other countries that attempted to address the question of real economy effects of increased capital requirements using their own general equilibrium or reduced form models. In this section, we briefly report their results that are presented in Table 1.

The Minneapolis Plan[60]

The Minneapolis Fed presented its "Minneapolis Plan" in November 2016. The Plan is a proposal for sharply increased capital requirements with the aim of ending the existence of 'too big to fail' financial institutions in the United States. Part of the plan entails increasing capital levels held by the banks and weighing the benefits thereof against the costs. The cost analysis proceeds in two steps and in the second step, the effects of higher lending spreads on GDP are estimated.

To translate the increase in lending spreads into a GDP effect, the Fed's FRB/US model is used. It is a substantial macroeconometric model containing approx. 300 equations used for forecasting, simulating scenarios and evaluating policy options.[61] The model does not include a banking sector, but it includes a range of different interest rates. The increase in the loan spread is assumed to affect commercial lending. The results from the FRB/US model suggest that a permanent 10 bps increase in lending spreads would reduce the GDP level annually by 0.10 per cent in equilibrium.

Bank of England (2015) calculations

A recent Financial Stability Paper published by the Bank of England uses the two-step approach to estimate real economy effects of increased capital requirements (Brooke et al., 2015). The authors use a set of semi-structural macroeconomic models (not further specified) in order to translate the estimated increase in the lending spread into the GDP effect. Their results suggest that a 10 bps increase in lending spreads could reduce output by up to 0.05 per cent in equilibrium. The authors note that their assessed cost is lower than the estimates from the LEI report, published by the Basel Committee in 2010 (BCBS, 2010).

Locarno (2011), BIQM model

Locarno (2011) assesses the impact of Basel III on the Italian economy with the use of a BIQM (Bank of Italy Quarterly Model), which is a semi-structural large-scale macroeconometric model. The study assesses that an increase in lending spreads of 12 bps can lead to maximum GDP decline that occurs during the transition period in the range of 0.03–0.39 per cent. Using a different approach (not specified in the paper), Locarno (2011) reports that in the steady state, the decline in GDP is estimated to be 0.18 per cent as a response to a 1 percentage-point increase in the risk-weighted capital ratio. The study was used in the LEI report.

[59] In the model, the entrepreneurial wealth shock is the main driver of lending spreads. We look at impulse responses to this shock (persistence parameter is set at 1) in order to infer the GDP response.

[60] https://www.minneapolisfed.org/~/media/files/publications/studies/endingtbtf/the-minneapolis-plan/the-minneapolis-plan-to-end-too-big-to-fail-2016.pdf?la=en

[61] The FRB/US model is different from DSGE models as the expectations of agents are formed in a different way. They may be either consistent with the full knowledge of the model (as in DSGEs) or based on projections from estimated VAR models. The optimisation problems of the agents in the FRB/US model are more short-term, resulting in an effective planning horizon close to five years, as opposed to an infinite horizon in the DSGE models. Moreover, the FRB/US model allows for nonlinear interactions among endogenous variables, while most DSGE models are linearised around the steady state.

Gambacorta (2011), VECM model

Gambacorta (2011) uses a VECM (Vector Error Correction Model) estimated on the US data from 1994 to 2008 to assess the effects of Basel III reforms. Like Locarno (2011), it is a study that was used in the LEI report. Gambacorta (2011) reports steady-state effects of increasing the risk-weighted capital ratio by 2, 4 or 6 percentage-points. The estimates suggest that a 2 percentage-point increase in the capital to risk-weighted assets ratio leads to a GDP decrease of 0.19 per cent and a decrease in lending of 0.36 per cent. The effect is almost linear, so for a 1 percentage-point increase in the capital to risk-weighted assets ratio, the GDP decline is around 0.09 per cent. If we assume that risk-weighted assets correspond to around 50 per cent of total assets, the results would suggest that a 1 percentage-point increase in the capital to total assets ratio corresponds to a fall in GDP of 0.18 per cent.

Conclusion

In this short note, we present various estimates of the GDP effects of higher capital requirements on the Swedish economy in the long run. Our one-step analysis using the Iacoviello (2015) model suggests that raising the non-risk-weighted capital ratio by 1 percentage-point can lower the long-run GDP level by about 0.13 per cent. In our two-step analysis, the increase in lending spreads due to higher capital requirements is taken as given, and the GDP response is calculated using RAMSES, a DSGE model developed at the Riksbank and estimated on Swedish data.[62] This experiment suggests that a 16 basis-point increase in lending spreads (corresponding to a 1 percentage-point increase in the non-risk-weighted capital ratio) could lead to a fall in GDP of around 0.09 per cent.

How do our results compare to other studies? Generally speaking, more recent studies suggest a GDP response to higher lending spreads and capital requirements in the ballpark of our estimates obtained with Iacoviello(2015) and RAMSES, while older studies, such as those used in the BSBC (2010) calculations, suggested larger effects.[63]

Given that we have access to new data and new types of models compared to 2010, when models incorporating banking and financial frictions were at an early stage of development in the wake of the global financial crisis, we believe that some of the earlier estimates of the impact of higher capital levels on economy need to be reassessed with the use of new data and methods. Furthermore, it is important to note than in many DSGE models, like Iacoviello (2015) that we use in our analysis, the Modigliani-Miller offset is absent, so if we were to consider the possibility that banks' shareholders may demand lower return on equity, when the banks become more capitalised, the ultimate increase in lending spreads, and thus, the GDP effect, would be even lower. As discussed in Appendix A, many studies report evidence of a Modigliani-Miller offset of at least 40–50 per cent.

[62] The extent to which higher capital requirements will increase lending spreads is an empirical question and it has not been examined for Sweden yet. That is why, in the first step of the two-step analysis, we need to rely on estimates for other countries.

[63] While comparing the effects of different studies it is important to account for the difference in capital ratio used therein. Given that risk-weighted capital ratios are country-specific and the increase in them can be driven both by an increase in capital and by a decrease in risk weights, we choose the more rigorous approach and examine the effects of an increase in the non-risk-weighted capital ratio. Thus, any translation of our results into risk-weighted capital ratios has to be time-dependent, taking into account the levels of capital, assets and bank risk weights in a given period of time.

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Appendix C - The economic cost of financial crises

Gabriel Söderberg

Introduction

Financial crises have historically involved large social costs. Most recently, the global financial crisis that started in 2007 led to a severe downturn in the global economy. Moreover, ten years after its outbreak, recovery remains sluggish in many parts of the world. The question of how costly a future financial crisis will be is highly relevant for determining an appropriate level for capital requirements for banks.

This memo gives an overview of the economic costs of financial crises. Past experience of financial crises is a good starting point for assessing the expected cost of any future crisis. The literature on how to estimate the cost of a financial crisis is, however, still in its infancy.[64] We summarise recent research drawing on past experience from a large number of countries, as well as some studies that look specifically at the Swedish crisis in the 1990s. There are reasons to expect a financial crisis to be particularly costly for an economy like that of Sweden. Based on existing empirical estimates of the cost of the Swedish crisis in the 1990s, our assessment is that the cost of a future Swedish crisis could be in the vicinity of 180 per cent of GDP in present value terms, or possibly even higher.

Methods for estimating the cost of a crisis

In the literature, the cost of a crisis is typically defined in terms of foregone output, expressed as a reduction in gross domestic product (GDP). This definition facilitates comparisons between different crises but also disregards the social costs of a crisis, which are not adequately captured in GDP statistics. Government bailouts of the banking sector, as well as fiscal stimulus, might reduce the fall in GDP, but lead to lasting government debt problems. Some costs are also borne unequally. For example, individuals who become unemployed as a result of a crisis are likely to suffer larger welfare losses in both the short and the long run, compared to those that retain their jobs throughout the crisis. An increase in unemployment following a crisis can lead to losses in job skills, which tends to make it more difficult for the individuals concerned to secure future employment. In addition, it has been argued that economic conditions caused by a financial crisis might fuel political extremism with far-reaching social consequences.[65]

Empirical estimates of the output loss, in terms of national GDP, that follows from a financial crisis differ considerably.[66]. The dot-com bubble in 2001 was not particularly costly in terms of real economic effects, while the subprime crisis in 2008 entailed substantial costs. Financial crises also appear to be more costly in developed countries than in less-developed countries.[67]

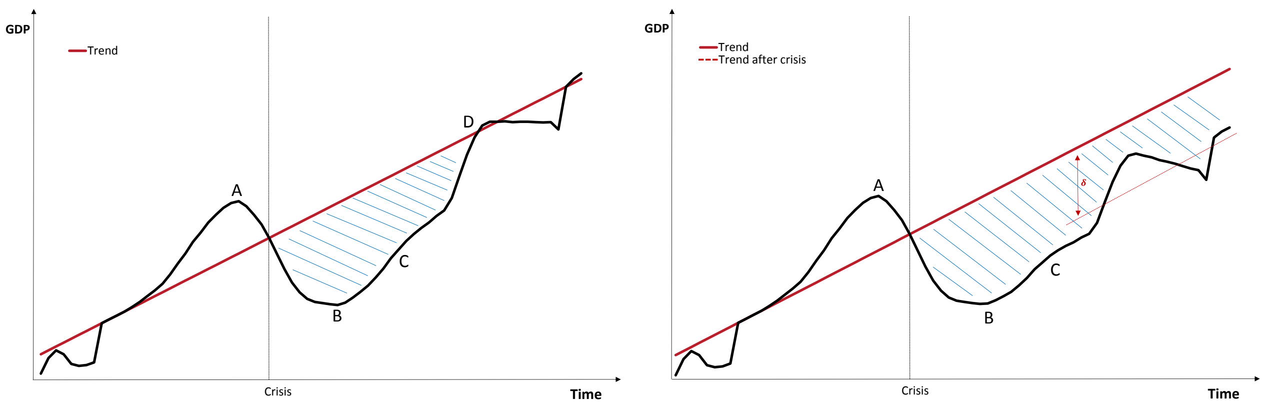
Moreover, there is no universal definition of a financial crisis. With a narrow crisis definition, for instance only crises that are systemic in nature, the sample will contain fewer and often larger crises, which tend to increase the estimate. A broad definition of crisis instead means that the sample will include a greater number of small crises, which reduces the estimate. An example of this is Romer and Romer (2015) which uses a very broad

[64] Haldane (2010).
[65] Bromhead et al. (2012).
[66] Haugh et al. (2009), p. 24.
[67] Hoggarth et al. (2002), Cerra and Saxena (2008).

definition of crisis: a rise in the cost of credit intermediation.[68] With this broad definition Sweden had eight financial crises between 1992 and 2010. Unsurprisingly, given this broad definition, the paper finds that the impact of financial crisis tends to be moderate.

Another difference between studies, with significant implications for their results, is the end point of the cost estimate. In particular, the results are typically highly sensitive to whether the effects of a crisis on the GDP level are assumed to be temporary or permanent.[69] In Chart 1 the example on the left shows a hypothetical economy in which the financial crisis results in output loss, but the economy subsequently recovers to the pre-crisis growth trend. The example on the right, in contrast, shows an economy in which the crisis has a permanent effect and the economy is shifted onto a lower growth trend.

Figure 1. Assessing the costs of financial crisis



Source: BCBS (2010), p. 9.

Chart 1 also illustrates four different approaches to setting start and end points of cost calculations:[70] (i) From the pre-crisis peak in GDP to the lowest point before GDP starts to increase again (between point A and B). (ii) From the pre-crisis peak to the point where the GDP growth rate, i.e. the slope of the curve, returns to its pre-crisis level (A to C. (iii) From the pre-crisis peak until the GDP level returns to its pre-crisis growth trend (A to D in the left-hand example). (iv) Allow for permanent effects of the crisis whereby the economy shifts to a lower growth path. The difference between the pre- and post-crisis trend is denoted δ in Chart 1.

Permanent effects and cumulative losses mean that the cost of the crisis is measured during all years from the onset of the crisis and over an infinite horizon. This is not as dramatic as it sounds. In effect, it means that a crisis entails "lost" years that are not subsequently recouped. The economy returns to its pre-crisis growth rate, but the lost years mean that in each subsequent year the GDP level is lower than it would have been without the crisis.

In case of permanent effects the present value of the future output loss can be calculated according to the following formula:

$$Cumulative\ loss = \frac{\delta}{1-\alpha}$$

where $\alpha = \frac{1}{1+r}$ and r is the discount rate.[71]

[68] Romer and Romer (2015), p. 8.
[69] In many studies there is no explicitly stated assumption about whether the effect is permanent or temporary. However, if only measuring the cost between a start and an end point, permanent costs are not taken into account. For the sake of simplification, we will refer to such studies as estimating non-permanent effects.
[70] This section is based on BCBS (2010).
[71] BCBS (2010), p. 34.

Some studies seek to estimate the reduction in GDP during a specific year, or during a specified interval immediately following the crisis such as peak-to-trough. Such short-run estimates will invariably look modest compared to estimates of the cumulative effect of a lower GDP level in the future. The difference is particularly stark if the crisis is assumed to have permanent effects, in which case the economy never returns to its pre-crisis growth path. One way to arrive at cumulative estimates based on such studies is to calculate the present value under the assumption that the estimated short-run effect persists into the future (see for example the studies listed as Infinite horizon (permanent effects) in Table A1.1 in BCBS, 2010).[72]

Literature review

We review the literature in two parts. The first part covers studies that estimate short-run effects of financial crisis, i.e. costs from the onset of the crisis to point B, C, or D in Chart 1. The second part covers studies that look at costs in the long run.

Short-run effects

Using a sample of 15 developed countries and 22 less-developed countries, Hoggarth et al. (2002) estimate the difference between trend and actual output during a crisis. They find that the cumulative effect of a financial crisis for developed countries on average amounts to around 21 per cent of annual GDP, and around 16 per cent for less-developed countries. These estimates refer to the cumulative effect during the crisis itself, but do not take into account long-run effects on the GDP level.

Laeven and Valencia (2008) estimate the cost in terms of GDP from the crisis and the three following years. This results in estimates ranging from zero per cent of GDP to around 100 per cent with a mean of around 20 per cent. An update, Laeven and Valencia (2012), includes a larger sample and an estimate of the cost of the 2007–2008 financial crisis. The average output loss for the latter is estimated to be 23 per cent of annual GDP in the euro area and 31 per cent in the United States.

Based on the definition and database of Laeven and Valencia (2008), Cecchetti et al. (2009) finds “tremendous diversity” in the outcomes of different crises.[73] Cost is measured as the cumulative loss in GDP over the duration of the crisis in per cent of its pre-crisis peak level. Using this method ten out of the 40 crises in the sample are found to have losses of above 25 per cent of pre-crisis GDP.

Haugh et al. (2009) studies the effects of financial crisis using OECD data on the gap between output and potential output. The conclusions are that the costs varied between different crises in different countries, with the crisis in the early 1990s of Japan being the only one that permanently seems to have lowered the country’s growth rate.

Long-run effects

Some studies analyse whether a financial crisis can be expected to have permanent effects on GDP, but without estimating the size of the effect. For example, Cerra and Saxena (2005) argued that Sweden’s financial crisis in the 1990s led to a *permanent* reduction in GDP. Cerra and Saxena (2008) use a sample of 190 countries to find further evidence that the output loss is highly persistent. Ramírez (2009) instead studies the effects of a single crisis, that of 1893 in the United States. The results suggest that states which experienced the financial crisis, such as Nebraska, had lower growth than states that were unaffected, such as West Virginia, for a long time after the crisis had been resolved. This suggests that effects of financial crisis are long-term. Abiad et al. (2009) likewise find that the growth rate in general tends to return to its pre-crisis level in the medium run, but not the pre-crisis trend. This would imply permanent or at least long-term effects of the crisis.

[72] Hoggarth et al. (2002), p. 837; BCBS (2010), p. 33.
[73] Cecchetti et al. (2009), p. 12.

Other studies seek to estimate the size of a long-run effect. Boyd et al. (2005) estimates the actual cost of financial crises in a sample of 23 countries selected from both developed and less developed countries. The study estimates output loss in per cent of the real GDP of the year preceding the crisis year, both assuming that the effect of crisis is permanent and non-permanent. The estimates vary with a mean of 95 per cent for non-permanent effects and 302 per cent for permanent effects.

Haldane (2010) assumes different levels of output loss from the global financial crisis in 2007–2008 that is permanent (ranging from 25 to 100 per cent). Given these assumptions, the results range from between 130 and 520 per cent of annual GDP for the UK, and between 90 and 350 for the world.

BCBS (2010) puts together a large set of different estimations, encompassing many different methodologies in order to assess the benefits of higher capital levels. For estimates assuming non-permanent effect, the median is 19 per cent of pre-crisis GDP, and for estimates assuming permanent effects, 158 per cent. Putting together both non-permanent and permanent estimates, the median is 63 per cent. Since the study includes both assumptions of non-permanent and permanent effects, the benchmark cost of a crisis for assessing the benefit of higher capital levels is set at 63 per cent of pre-crisis GDP.

Recent research indicates that the cost of a financial crisis may be higher than previously thought. In particular, experience since the outbreak of the recent global financial crisis suggests effects that are more severe than initially expected. Ball (2014) finds that the effect of the financial crisis was very diverse across countries, but that there was evidence for strong long-term effects. The weighted average output loss in the year 2015 alone was estimated at 8.4 per cent.

Fender and Lewrick (2015) translates the one-year estimate from Ball (2014) to a present value of future output losses, assuming permanent effects, to find an implied a cost of 180 per cent of pre-crisis GDP.[74] Using this and other recent estimates, the study subsequently updates the 63 per cent estimate of BCBS (2010) to 100 per cent to account for the economic downturn of the global financial crisis proving to be longer, and hence the cost of the crisis higher, than was expected in 2010.

Table 1 summarises the results of the studies discussed above.

Table 1. Estimates of the cumulative cost of financial crisis

Per cent of GDP

Study	*Mean*	*Min*	*Max*	*Assumption*
Hoggarth et al. (2002)[75]	16	0	122	Non-permanent
Laeven and Valencia (2008)	20	0	123	Non-permanent
Haugh et al. (2009)	21	10	40	Non-permanent
Cecchetti et al. (2009)	18	0	129	Non-permanent
Boyd et al. (2005)*	97	0	194	Non-permanent
Boyd et al. (2005)**	302	0	1041	Permanent
BCBS (2010)*	19	0	130	Non-permanent
BCBS (2010)**	145	0	1041	Permanent
Haldane (2010)	268	90	500	Permanent
Ball (2014)*	8.4	0	35	Non-permanent
Ball (2014)**[76]	180	0	1035	Permanent

Note: For studies in which estimates for both non-permanent and permanent effects are given, the non-permanent are marked with * and permanent effects are marked with **.

[74] BCBS (2015), p. 48.

[75] Estimates are for industrial countries, using GAP2 methodology. See Hoggarth et al. (2002) for further details.

[76] Re-estimated for mean by Fender and Lewrick (2015), and maximum by the present author.

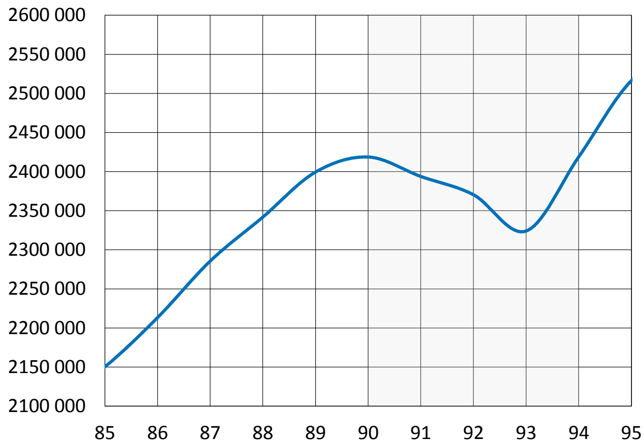
Cost of a Swedish financial crisis

The banking crisis that Sweden experienced in the early 1990s sheds some light on the possible magnitude of a future crisis in Sweden. On one hand some factors suggest that this cost might have increased. Above all the Swedish banking sector has grown substantially since the early 1990s. In the year before the crisis the assets of the Swedish banking sector accounted for roughly 100 per cent of GDP.[77] Today the number is closer to around 350 per cent of GDP. Problems in a proportionally bigger banking sector, all else being equal, are likely to have a greater impact on an economy. On the other hand some factors including a number of reforms since the 1990s suggest a lower cost. These reforms include for instance independence of the central bank, new regulations and new resolution framework. It is difficult to objectively weigh these different factors against each other, so our best estimate, is that it is not unlikely that the cost of a future crisis in Sweden might be similar to that of the 1990s.

Effects of the 1990s crisis

The financial crisis of the early 1990s entailed a significant decline in economic output between the start and the end of the crisis (Chart 2).

Chart 1. Swedish real GDP
Million, SEK



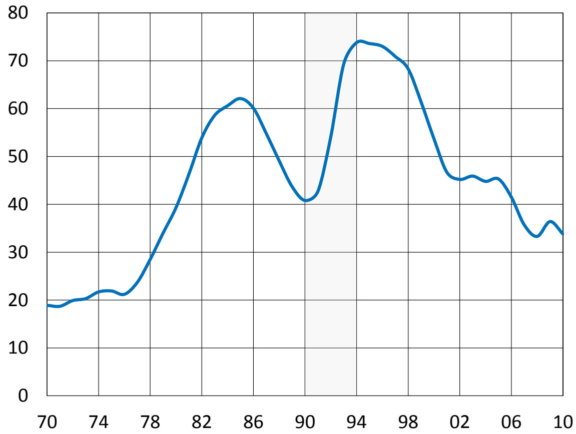
Source: National Institute of Economic Research

The crisis entailed considerable public costs. Government debt increased sharply (Chart 3), in part due to a government bailout of the banking sector, but also to a crisis-induced reduction in tax revenues and increases in public expenditures.

[77] Based on calculations from Statistisk årsbok för Sverige 1992, p. 224, 277.

Chart 2. Swedish government debt

Per cent of GDP

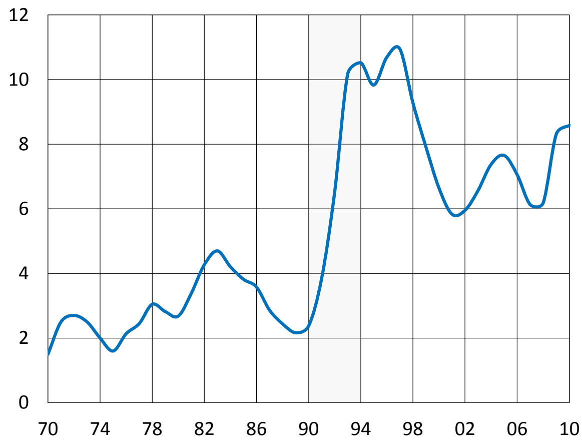


Source: Swedish National Debt Office

Unemployment increased from around two per cent to around ten per cent (Chart 4). When the crisis was over, unemployment was reduced, but settled on a level that was higher than before the crisis. Although there are several potential reasons for this increase, one interpretation is that the crisis brought on a permanent increase in unemployment.[78]

Chart 3. Swedish unemployment rate

Per cent of workforce

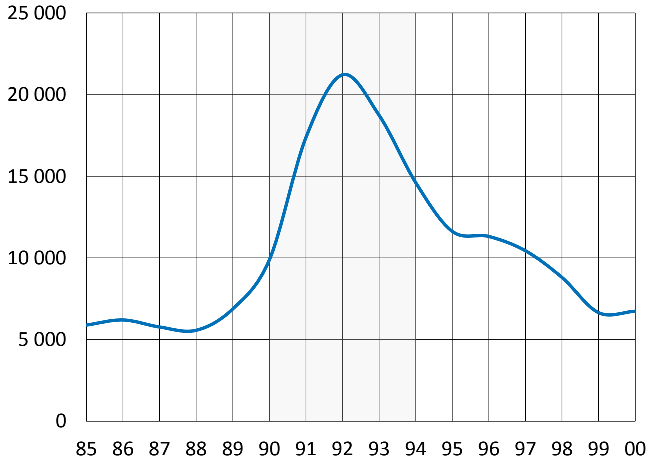


Source: Statistics Sweden

The crisis also caused an upsurge in the number of bankruptcies (Chart 5).

[78] Cerra and Saxena (2005).

Chart 4. Total number of bankruptcies for companies in Sweden



Source: Compiled from Statistical Yearbooks of Sweden

Against a backdrop of sharply increased default rates and high unemployment levels, the number of heavily indebted individuals grew. New legislation enacted in 1994 to mitigate the problem was only partially successful. In 2013 there were still 95,000 people who had debt with the Swedish Enforcement Agency (*Kronofogdemyndigheten*) that originated from around the time of the 1990s crisis.[79]

What would the output loss of a Swedish crisis be?

Several factors suggest that the cost of crisis in Sweden can be expected to be higher than an international mean. The Swedish banking sector is large in relation to the size of the economy, equivalent to approximately 350 per cent of GDP. In addition, it is highly concentrated, dominated by four major banks that are highly interconnected. Banks also play a dominant role in the provision of credit to companies and households: the corporate bond market is small, and mortgages are provided by banks and are typically not securitised. This implies that alternative sources of finance may be more difficult to access if Swedish banks are under stress, suggesting that a banking crisis would result in a more severe credit crunch than in less bank-oriented economies. Overall, these factors indicate that a future Swedish crisis could be more severe than an international mean.

There have been a number of attempts to estimate the cost of the Swedish crisis in the 1990s (see Table 2 for summary of different estimates of the cost of a crisis in Sweden). Most of them however only assume non-permanent effects which risks understating the cost in the event of the effects being permanent or long-run.[80] The study that has been chosen here as the benchmark estimate for the cost of the 1990s crisis is Boyd et al. (2005). The main reason is that it is the only study that estimates a cumulative net present value cost of the 1990s crisis in Sweden assuming both non-permanent effects and permanent effects and within a coherent framework. Assuming non-permanent effects, Boyd et al. (2005) estimate the cost to be around 101 per cent of GDP, and 257 per cent assuming permanent effects.[81]

In order to reach a baseline estimate, the average of the estimates of the cost for non-permanent and permanent effects is calculated. The result is roughly 180 per cent of pre-crisis GDP. An estimated cost of crisis of 180 per cent can be compared to the updated international median estimated by Fender and Lewrick (2015) at around 100 per cent. Based on Ball (2014) Fender and Lewrick (2015) also reach the number of 180 per cent for the

[79] SOU 2013:78, p. 37.
[80] See Laeven and Valencia (2008), Haugh et al. (2009), Cecchetti et al. (2009).
[81] Boyd et al. (2005) also performs a calculation in which the end point of summing the costs is simply when they run out of actual data. The authors note that this is "surely inappropriate" and so we ignore this number (Boyd et al., 2005, p. 994).

financial crisis of 2007–2008.This result is based on the assumption of a discount rate of 5 per cent. Recent analysis suggests however that equilibrium interest rates may have declined which would suggest that using a lower discount rate would be appropriate.[82] In general a lower discount rate means that the present value of the future output loss increases, pointing to a higher cost of crisis. This serves to strengthen our argument that our estimates are high but not unreasonable.

Table 2. Ballpark estimate of the cost of a future systemic Swedish financial crisis
Per cent of pre-crisis GDP

Estimate	Cost (per cent of GDP)	Comment
Sweden, crisis 1990–1994		
Boyd et al. (2005), non-permanent	101	
Boyd et al. (2005), permanent	257	
International average		
Fender and Lewrick (2015)	100	
Ball (2014)	180	Re-estimated by Fender and Lewrick (2015)
Riksbank (2017) baseline estimate	**180**	**Average of Boyd et al. (2005) high and low**

Conclusion

In the above, we have described common approaches to estimating the cost of financial crises and reviewed relevant empirical literature. We have argued that there are reasons to expect a financial crisis to be particularly costly for an economy like that of Sweden. Drawing on existing empirical estimates of the cost of the Swedish crisis in the 1990s, our conclusion is that the cost of a future Swedish crisis could amount to 180 per cent of GDP in present value terms, or possibly even higher. This estimate is broadly in line with other comparable studies. While recognising the uncertainty surrounding estimates of this kind, we conclude that existing research provides strong support for the notion that financial crises can entail very large social costs.

[82] Sveriges Riksbank (2017), p. 14–17.

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Appendix D - Structural estimates of the probability of a banking crisis at different levels of capital

Markus Andersson and Daniel Buncic

Introduction

The probability of a banking crisis is linked to the default probability of individual banks. A large body of literature deals with the estimation of default probabilities of individual firms. While the nature of banking activities make banks a distinct type of firm, we can nonetheless draw on this literature to shed some light on the default probability of banks.

In essence, there are two different approaches to modelling probabilities of default. One is reduced form, the other is structural. Reduced form models approximate the properties of the observed data as closely as possible without being confined by potentially constraining assumptions of a theoretical model. Structural models are derived from asset pricing theory and require clear definitions about the stochastic properties of the process of interest.

We implement a standard structural probability of default (PD) model based on Merton (1974). The Merton model is commonly used as a benchmark structural PD model when new models are proposed (see for instance, Bharath and Shumway, 2008; and, with an application to banks, Nagel and Purnanandam, 2016), and is still widely used by specialised practitioners in the financial industry.

While the standard Merton model approach provides a benchmark, we are aware that it has several drawbacks when it comes to estimating the probability of default of a bank (some of these are discussed further in a more general setting in Nagel and Purnanandam (2016) and others). In particular, the estimated PDs are sensitive to the volatility of the banks' assets, which is an unobserved process and needs to be estimated from data. Moreover, once the distance to default is determined from the model parameters, the likelihood of default is determined under a normal or Gaussian distribution, which does not allow for fat tails, a feature commonly encountered with data on historical bank losses. This property of the Merton model based PD estimates is likely to indicate a larger reduction in the probability of default for increasing levels of capital and for a fixed level of volatility than seems plausible from empirically observed loss distributions. In Appendix E of this staff memo, a reduced form analysis is presented which uses a long time-series of historical losses in the entire Swedish banking system and a more flexible statistical model that is not confined by the assumptions of a theoretical model, to offer a contrasting approach.

While recognizing the drawbacks of the Merton model, the intention of this study is to perform a scenario based analysis of the probability of default obtained from a standard and well known model for different levels of capital. More specifically, we ask the following question: "What is the likelihood of a banking crisis at different levels of capital, assuming that asset value volatility can take on values that have historically been experienced in the Swedish data?" We show that more equity in relation to total assets significantly reduces the probability of a banking crisis.

Modelling the probability of default of a bank

In the Merton model, Equity (E) is a call option on the "Value" (V) of the assets of a firm, with a strike price equal to the face value of Debt (D), due at maturity T.[83] Equity is defined by the Black-Scholes-Merton (BSM) equations as:

$$
\begin{aligned}
E &= V\Phi(d_1) - \exp\left(-r_f T\right) D\Phi(d_2) \\
d_1 &= \frac{\ln\left(\frac{V}{D}\right) + (r_f + 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}} \\
d_2 &= d_1 - \sigma_V\sqrt{T}\,,
\end{aligned}
\tag{1}
$$

where r_f is the risk-free rate, Φ is the cumulative density function (cdf) of a standard normal random variable, and σ_V is the volatility of V. From the (option's) delta of the equity, equity volatility is related to asset volatility by:

$$\sigma_E = \frac{V}{E}\Phi(d_1)\sigma_{V,} \tag{2}$$

where σ_E is equity volatility. The above results are derived under the assumption that the value of the assets of a firm follows a Geometric Brownian Motion (or diffusion process):

$$dV_t = \mu_V V_t dt + \sigma_V V_t dW_t, \tag{3}$$

where W_t is Brownian motion (increments are standard normal), and μ_V is a drift term, so that the log of the V_t process is distributed normal:

$$
\begin{gathered}
\ln(V_t) \sim N(\ln(V_0) + (\mu_V - 0.5\sigma_V^2)T, \sigma_V^2 T) \\
\text{or} \\
\ln(V_T) = \ln(V_0) + (\mu_V - 0.5\sigma_V^2)T + \sigma_V\sqrt{T}Z_T,
\end{gathered}
\tag{4}
$$

where Z_T a is standard normal distributed random variable. Default occurs when $V_T < D$, i.e. the value of a firm's assets at maturity T are less than the debt obligation D payable at maturity. Using the relations above, the probability of default is then defined as:

$$
\begin{aligned}
\Pr(V_T < D) &= \Pr(\ln(V_T) < \ln(D)) \\
&= \Pr\left(\ln(V_0) + (\mu_V - 0.5\sigma_V^2)T + \sigma_V\sqrt{T}Z_T < \ln(D)\right) \\
&= \Pr\left(\sigma_V\sqrt{T}Z_T < \ln\left(\frac{D}{V_0}\right) - (\mu_v - 0.5\sigma_V^2)T\right) \\
&= \Pr\left(Z_T < \frac{\ln\left(\frac{D}{V_0}\right) - (\mu_v - 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}}\right).
\end{aligned}
\tag{5}
$$

[83] The Merton model assumes that debt is a zero-coupon bond with face value D and maturity T. Moreover, markets are assumed to be frictionless, i.e., there are no transaction cost or any other fees, and that the firm cannot pay out dividends or issue new debt. For a full list of assumptions underlying the Merton model, we refer the reader to the review by Sundaresan (2013). Sundaresan (2013) also offers a discussion on how reasonable these assumptions are.

The fraction in the last expression in (5) can be rewritten as:

$$\frac{\ln\left(\frac{D}{V_0}\right) - (\mu_v - 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}} = -\frac{\ln\left(\frac{V_0}{D}\right) + (\mu_v - 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}} = -dd, \tag{6}$$

where

$$dd = \frac{\ln\left(\frac{V_0}{D}\right) + (\mu_v - 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}}. \tag{7}$$

The term *dd* is known as the "distance to default". The probability of default follows as:

$$\Pr(V_T < D) = \Phi(-dd). \tag{8}$$

Two of the key inputs into the Merton model pricing equations are the *market value* of assets of the firm (*V*), and its volatility (σ_V). Since these two are unknown and/or unobservable, they are obtained from the BSM option pricing relations defined by:

$$\begin{aligned} E &= V\Phi(d_1) - \exp\{-r_f T\}\, D\Phi(d_2) \\ \sigma_E &= \frac{V}{E}\Phi(d_1)\sigma_V, \end{aligned} \tag{9}$$

for given values of *E*, r_f, *D*, σ_E, and time to maturity *T*.
To solve for *V* and σ_V in (9), the following inputs are required:

1) The market value of equity (*E*). This is computed as the number of outstanding shares on issue (Bloomberg Code: EQY_SH_OUT) multiplied by the stock price (Bloomberg Code: PX_LAST).
2) Equity volatility σ_E. This is estimated from daily log returns of the stock prices, where returns are computed as $\ln\left(\frac{P_t}{P_{t-1}}\right)$.
3) The risk-free rate r_f. We use the one year treasury (government) rate (Bloomberg Code: C2591Y Index). We set a floor for the risk-free rate of 10 basis points (bp).
4) The face value of debt *D* at maturity. We take total liabilities for debt (Bloomberg Code: BS_TOT_LIAB2).

We source all data from Bloomberg. Due to the different frequencies of the series used, the starting dates as well as the length of the available samples differ across banks and variables. For instance, equity prices as well as the risk-free rate are available at daily frequencies from 2nd of January 1990 for SEB, 4th of January 1993 for SHB, 9th of June 1995 for Swedbank, and 8th of December 1997 for Nordea, and from 25th of February 1994 for the one year rate. Both, the book value of Debt (total liabilities) and the number of outstanding shares on issue are accounting data and are only available at a quarterly frequency. Debt data start in March 1997 for SEB and SHB, and March 1999 for Nordea and Swedbank, while the number of shares outstanding are available from March 1992 for SHB, June 1995 for Swedbank, and March, respectively, June 1998 for Nordea and SEB. All daily data end on 27th of April 2017, while the quarterly series are available until the end of March 2017.

We follow standard practice and use total liabilities as the face value of debt (see Bharath and Shumway (2008), page 1344 and Crosbie and Bohn (2003) page 7). While it is possible that firms may continue to trade once total liabilities exceed the value of their assets due to the long-term nature of some of their liabilities, which may not require servicing at maturity *T*, it is true that the default point lies somewhere between total liabilities and current/short-term liabilities. Taking total liabilities as the default point is thus more conservative and is the common approach in practice (see also the discussion on page 7 in Crosbie and Bohn (2003)).

As is discussed in more detail on pages 10–11 in Crosbie and Bohn (2003), it is the *market value* of the firm's assets that matters for the probability of default in the Merton model, and therefore for the firm that is analysed. The interest rate spread that firms pay over the default-free rate is directly linked to the market's perception (pricing) of the firm's ability to service and repay its debt obligations. Put differently, the (default) risk premium that is paid by the firm is a function of the market's computed probability of default. As market prices of assets are "forward-looking", so will be the market price of the value of the firm, and thus also its PD. The book value of the firm is a backward-looking variable.

For a fixed level $\ln\left(\frac{V_0}{D}\right)$ in (7), it is the volatility of the firm's asset value (σ_V) that is the key parameter in the Merton model. Given the link between asset value volatility and equity volatility in (9), and the empirical fact that equity volatility is not time-invariant, it should be clear that asset value volatility (σ_V) is also time-invariant. It thus seems unlikely that the simple diffusion specification in (3) with time-invariant volatility is a realistic process for V_t. Further, (unconditional) asset returns are known to exhibit "fat tails". A convenient way to address these deficiencies is to specify a time-varying volatility process. Moreover, it is well known that rescaling unconditional asset returns by an appropriate measure of asset variability will substantially reduce, if not eliminate, "fat tails" (see for example Corsi et al. (2013), p. 286, for an illustration of S&P 500 log-returns rescaled by an unconditional volatility and an appropriate "realised volatility" measure).

Nagel and Purnanandam (2016) discuss in more detail the importance of allowing for a time-varying volatility process and how low volatility states adversely reduce the probability of default in the Merton model (see in particular pages 16–19).[84]

To be able to capture volatility states (or changes in volatility) in equity returns and then map them to asset volatility, Nagel and Purnanandam (2016) use a 1-year (backward) rolling window of data to compute (time-varying) volatility (see page 21). The Merton model, nevertheless, requires forward-looking volatility over the horizon of the maturity of the asset of interest. This forward-looking volatility is commonly replaced by a backward-looking measure by practitioners, that is, either a 1-year rolling window as in Nagel and Purnanandam (2016), or a 3-year rolling window based on weekly equity return data.

We construct 1-year *forward* rolling window estimates of the volatility of equity. Our motivation for doing this is to be as consistent with the definition of volatility in the Merton model as possible. That is, we define equity volatility σ_E to be used in (9) to back out V_t and σ_V as the unconditional volatility computed from equity returns over the next 1-year horizon, that is, over the next 252 days. We roll forward through the sample to get daily estimates. Note that these 1-year forward rolling window estimates are numerically identical to the 1-year backward rolling window estimates, the approach used in Nagel and Purnanandam (2016). The only difference are the recorded time stamps. Our preference for using a 1-year *forward* rolling window is driven by the fact that we have the benefit of hindsight and know exactly how equity prices, and hence equity volatilities, have evolved over the year ahead from a given point in time, that is, over the maturity horizon considered in the PD calculations. Evidently, this is not feasible when wanting to construct real time PD estimates.

[84] Note here that the objective of Nagel and Purnanandam (2016) is not to model asset volatility, but to introduce a new double contingent claim-based default model that takes into account the fact that bank risk dynamics are non-linear in the sense that the upside is capped. However, what is clear from the discussion on pages 16–19 in Nagel and Purnanandam (2016), and also from the default probability plot comparison on page 24 (Figure 8 in their paper), is that the Merton model consistently underestimates default probabilities in low volatility states, while it performs reasonably (sometimes overstating PDs) in states of high volatility.

However, since our objective is to implement a scenario based analysis, where we compute PD estimates based on various historical asset value volatilities and different capital levels, our approach eliminates an additional layer of uncertainty with regards to one of the key input parameters in the model. In the analysis that follows, we use the percentiles of the estimated historical asset value volatilities σ_V in a scenario based analysis of the effect of different capital levels on the probability of a banking crisis in Sweden.

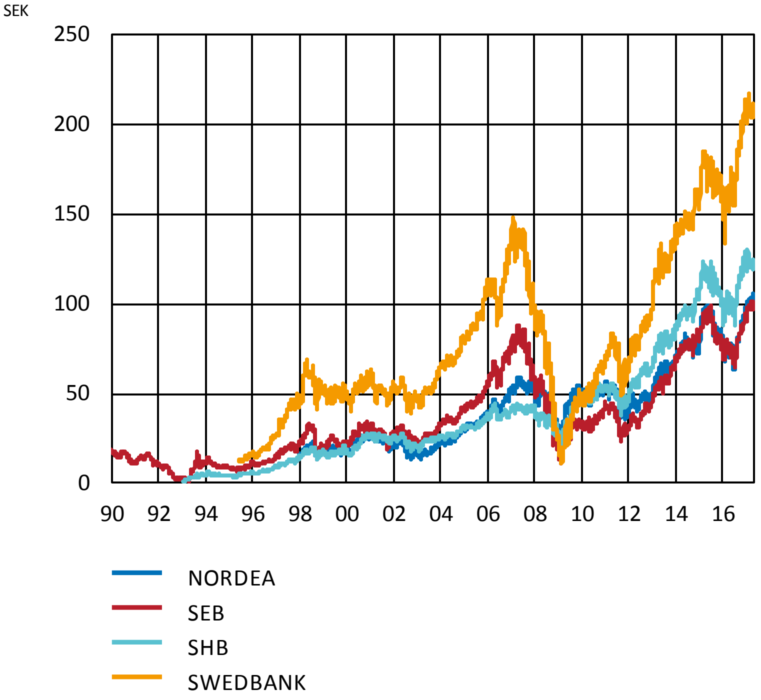
PD estimates of individual banks

To compute the PDs, we initially need to extract the unobserved components V_t and σ_V from the BSM option pricing relations in (9). As discussed above, we use (daily) 1-year forward rolling window estimates of the volatility of equity (σ_E) in (9). All remaining accounting data, i.e., the number of outstanding shares on issue and total liabilities (debt) are at quarterly frequencies. We create daily accounting data from the quarterly series and fill missing entries with the most recent known values from the quarterly series. Thus, if debt information (total liabilities) is available for the March quarter (31.03), we fill all following daily date entries with the same value until the June quarter figures are available from 30.06 onwards. For all PD calculations, we use a maturity horizon of one year.

Charts 1 to 3 below show daily time series plots of equity prices for the four largest Swedish banks (Nordea, SEB, SHB and Swedbank) together with estimates of (annualised) 1-year forward equity volatility (σ_E), and the corresponding 1-year forward asset value volatility (σ_V) computed from the Merton model relations in (9), all expressed in percent and plotted over the entire available data range for the respective series of interest. The first two charts illustrate the familiar relationship between equity prices and equity volatility. Volatility is generally low when equity prices are rising, and tends to rise when equity prices drop (the leverage effect). Moreover, equity volatility is time-varying and tends to cluster. Asset value volatility (σ_V), shown in the last chart, is also strongly time-varying and clusters. Note from chart 2 that the highest value of equity volatility (σ_E) of around 120 per cent for SEB occurs at the end of 1992. However, this highest level of equity volatility is not captured in our sample of asset value volatility (σ_V), due to the lack of accounting data (debt data start in March 1997 for SEB) needed to back out σ_V from the relations in (9). We think that this is important to highlight here and should be kept in mind when considering what equity volatility magnitudes seem plausible from a historical perspective, which are then used as an input in the *dd* formula for the construction of the scenario based PDs. That is, the maximum value of the observed historical 1-year forward equity volatility is 20 percentage points higher than the maximum in our sample for which debt data are available, i.e., from 1998 onwards.

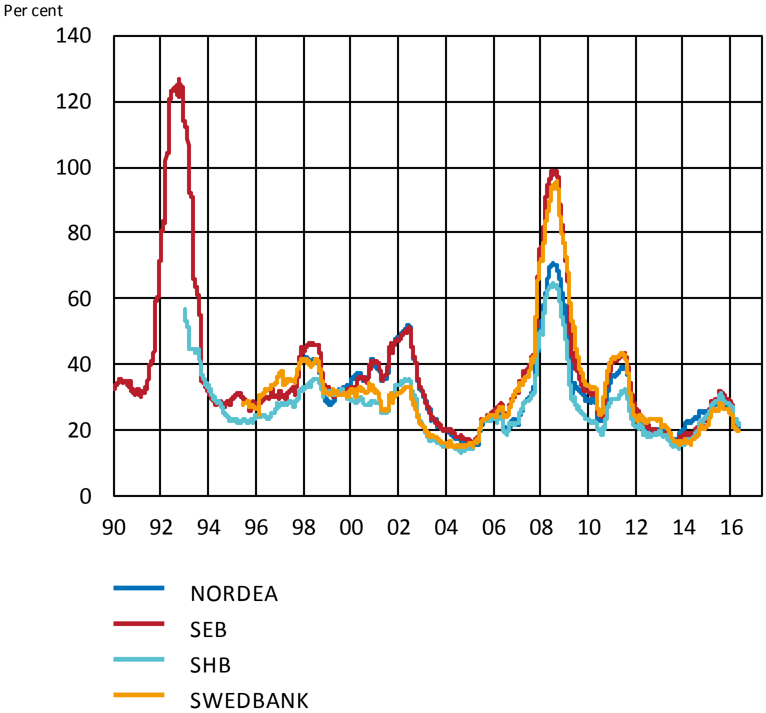
The direct impact of changes in σ_V on the probability of default in the Merton model is most clearly seen from the distance to default (*dd*) relation in (7), where σ_V not only enters in the denominator, which amplifies or dampens the magnitude of *dd*, but also in the numerator, which shifts the location of the mean (the $-0.5\sigma_V^2 T$ term).

Chart 1. Equity price, the four major Swedish banks



Source: Bloomberg

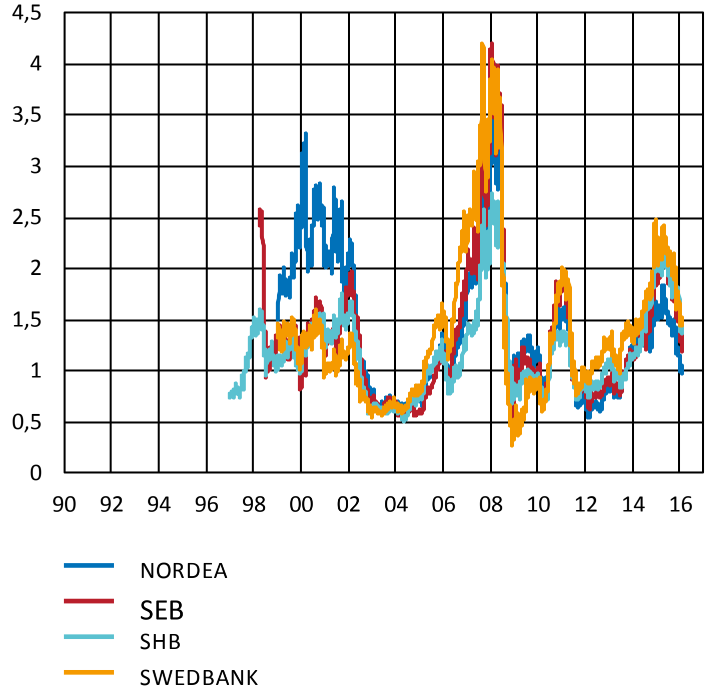
Chart 2. Equity volatility, the four major Swedish banks



Source: Bloomberg and the Riksbank

Chart 3. Asset volatility, the four major Swedish banks

Per cent



Source: Bloomberg and the Riksbank

In the analysis that follows, we consider a total of five different "plausible" values of asset value volatility σ_V that have historically been observed when we construct PDs for the four banks, and later on for the entire Swedish banking system. These are based on the 50th, 75th, 90th, 95th and 99th percentiles of σ_V. Two other inputs needed for the Merton model-based PD calculations to be implemented are the drift term of asset value (μ_V) and $\ln\left(\frac{V_0}{D}\right)$. We use the cross-sectional mean of the time series average of the book value of return on assets (ROA) to proxy the growth rate of assets. This value is around 0.62 per cent in the sample that is available to us. Overall, and with the exception of the 2008–2009 period, ROA seems to be a fairly stable process, ranging between 0.4 and 0.8 per cent (in annualised terms).[85] We set the drift term at 0.62 per cent for all four banks and all five scenarios.

The final input in the Merton model formula is the $\ln\left(\frac{V_0}{D}\right)$ term, that is, (log) assets over debt. Since we are interested in the effect of different levels of capital (Equity/Assets) on the probability of a banking crisis in Sweden, we rewrite the following relations as:

$$Assets = Debt + Equity$$

$$\frac{Assets}{Assets} = \frac{Debt}{Assets} + \frac{Equity}{Assets}$$

$$1 = \frac{Debt}{Assets} + Leverage$$

[85] One approach taken by practitioners is to use equity return data to compute a (log) return on equity from historical data, and then "deleverages" that return to obtain a measure of ROA that can be used to approximate the drift term μ_V. Using the historical (log) equity returns, the cross sectional mean of the time series averages is about 12 per cent (per annum) in our data. Average leverage across time and across the banks is about 23. This implies a deleverage return on equity of about 0.52 per cent, which is somewhat lower than our considered value of 0.62 per cent. In Riksbank (2011), the growth rate of assets was set to 0.75 per cent for all banks, which was based on a long history of US bank data. Our value of 0.62% is thus approximately in the middle of these two values. Alternatively, the drift term μ_V could be estimated using an iterative procedure where one first fixes the volatility μ_V at some initial value, then solves for V with the second equation in (9), compute log asset value returns, and then update the μ_V and σ_V estimates by their (unconditional) sample mean and standard deviation of the return sequence. The new estimate of σ_V is then plugged in the second equation in (9), solved for V, μ_V, and σ_V is recomputed. This process continues until convergence.

$$(1 - Leverage) = \frac{Debt}{Assets}$$

$$(1 - Leverage)^{-1} = \frac{Assets}{Debt}$$

$$-\ln(1 - Leverage) = \ln\left(\frac{Assets}{Debt}\right), \tag{10}$$

and replace $\ln\left(\frac{V_0}{D}\right)$ with $-\ln(1 - Leverage)$ in the *dd* relation in (7). The effective computation of the PDs based on different capital requirements is then based on the following modified distance to default (*dd**) formula:

$$dd^* = \frac{-\ln(1 - Leverage) + (\mu_V - 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}}. \tag{11}$$

We estimate the model for capital levels (or leverage ratios) ranging from 2 to 20 per cent of total assets. In the tables and discussion that follow below, we refer to the total equity to total assets ratio as the leverage ratio, or simply, as leverage.

An important question is what level of equity to total assets to consider as critical or a default point (see also the introduction or main document for additional discussion). We examine two cases. If the value of assets falls below the face value of debt, the firm is insolvent. This corresponds to an equity level of 0 per cent and is the first case we consider. Past experience, however, suggests that banks can run into serious difficulties also before equity is depleted. Setting the critical level at higher levels than 0 per cent results in higher PD estimates. One relevant level to consider is when the bank is violating existing capital regulations and risks either losing its licence or entering resolution. Current regulation focuses on risk-weighted ratios. In terms of equity to total assets, we let the level of 1.5 per cent represent this threshold, as an approximation. This is the second case that we consider.

Estimating the probability of a banking crisis

We use the model described above to generate (physical or historical) PD estimates for the individual banks. Taking these individual estimates as a starting point, we turn to the question of the probability of a banking crisis in Sweden. In order to map the PDs of the individual banks to the probability of a banking crisis – in effect, a PD for the banking system – we need to specify more clearly what a banking crisis is considered to be.

We define a banking crisis as the occurrence of one (or more) of the four large Swedish banks defaulting. The same assumption was made in Riksbank (2011). Given the high degree of concentration and interconnectedness in the Swedish banking system, we find this assumption to be reasonable. In addition, we take into account the historically observed positive and time-varying correlations between the banks' equity returns.

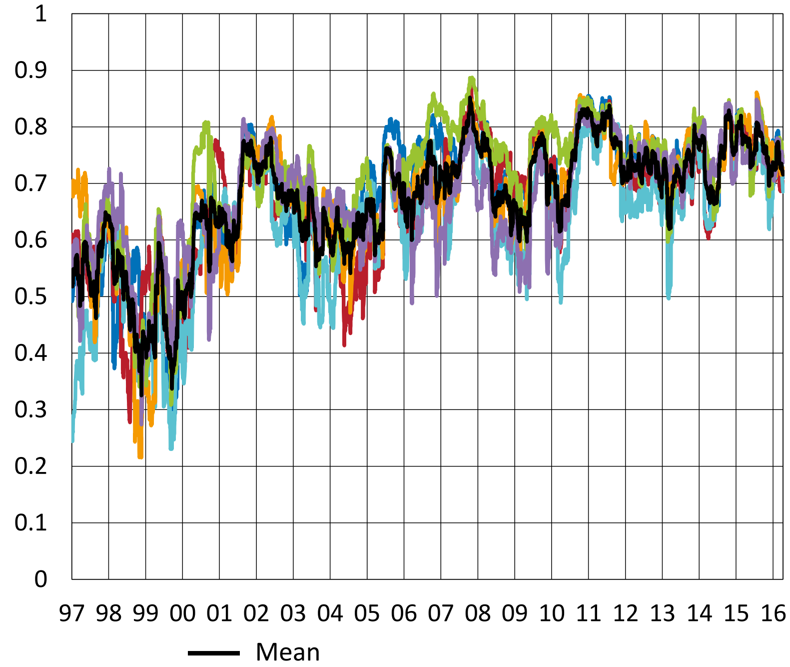
Given these assumptions, the probability of a banking crisis can then be obtained as 1 minus the probability of all banks *not* defaulting. Let dd_j^* denote the (modified) distance to default for bank *j*, with the probability of default for bank *j* in the Merton model given by $\Phi(-dd_j^*)$ or $1 - \Phi(dd_j^*)$. The probability of a bank not defaulting is thus $1 - \Phi(-dd_j^*) = 1 - \left(1 - \Phi(dd_j^*)\right) = \Phi(dd_j^*)$. To compute the joint probability of all banks not defaulting, we need to compute the joint cdf. For independent events, this joint cdf is the product of the marginal (individual) cdfs, so that the probability of all banks not defaulting is $\prod_{i=1}^{4} \Phi(dd_j^*)$. The probability of at least one bank defaulting thus follows as the complement:

$$1 - \prod_{i=1}^{4} \Phi(dd_j^*). \tag{12}$$

For dependent default events, we compute the joint cdf from the individual marginal cdfs, a correlation matrix *R*, and aggregate these using a Copula (linking) function. For consistency with the Merton model, we use a Gaussian Copula and estimate a time-varying correlation matrix of equity returns using the DCC GARCH model of Engle (2002). The six pairwise correlations that are estimated from the model are shown in the chart 4 below. We compute the cross-sectional average of the six pairwise correlations and superimpose a plot of this average in black in the chart below.

Chart 4 shows that all correlation pairs are always strictly positive, and that the correlations vary over a fairly narrow range between 0.4 and 0.8 for the largest part of the sample. Given the rather narrow variation in the correlations (correlations are defined over the -1 to 1 interval), we follow the approach used for the drift term and use a single correlation matrix *R* which corresponds to the "average" correlation matrix for all five considered scenarios. This correlation matrix is set to the one that corresponds to the time series mean of the cross sectional average correlations.

Chart 4. Pairwise correlations between the four major Swedish banks



Given the correlation matrices *R* and the individual banks' probabilities of not defaulting $\Phi(dd_j^*)$, we compute the joint probability of not defaulting as $C\left(\Phi(dd_1^*), \Phi(dd_2^*), \Phi(dd_3^*), \Phi(dd_4^*), R\right)$, where $C(\cdot)$ is the Gaussian Copula function. The probability of a banking crisis is again computed as the complement event $1 - C\left(\Phi(dd_1^*), \Phi(dd_2^*), \Phi(dd_3^*), \Phi(dd_4^*), R\right)$. Tables 1 and 2 below show these probabilities computed for correlated asset returns for the two examined threshold levels of equity less than zero, and equity less than 1.5 per cent of total assets, respectively.

Table 1. Equity less than zero, correlated assets
Per cent

Leverage ratio	99^{th} Percentile	95^{th} Percentile	90^{th} Percentile	75^{th} Percentile	50^{th} Percentile
2	41.95	33.24	25.61	13.12	4.06
3	29.97	19.99	12.66	3.79	0.40
4	19.97	10.66	5.25	0.79	0.02
5	12.38	5.02	1.82	0.12	0.00
6	7.13	2.09	0.53	0.01	0.00
7	3.80	0.75	0.12	0.00	0.00
8	1.87	0.24	0.02	0.00	0.00
9	0.85	0.06	0.00	0.00	0.00
10	0.35	0.02	0.00	0.00	0.00

Table 2. Equity less than 1.5 per cent of total assets, correlated assets
Per cent

Leverage ratio	99^{th} Percentile	95^{th} Percentile	90^{th} Percentile	75^{th} Percentile	50^{th} Percentile
2	61.39	57.51	53.66	45.61	35.54
3	48.40	41.02	34.16	21.55	9.89
4	35.76	26.17	18.41	7.34	1.40
5	24.68	14.83	8.34	1.80	0.10
6	15.87	7.43	3.16	0.33	0.00
7	9.49	3.28	1.00	0.04	0.00
8	5.26	1.27	0.26	0.00	0.00
9	2.70	0.43	0.05	0.00	0.00
10	1.27	0.12	0.01	0.00	0.00

We also consider the scenario where bank defaults are independent of one another ("uncorrelated assets") as an alternative, where the joint cdf is computed as the product of the marginal cdfs of the individual banks, with a banking crisis again defined as in (12) before. However, to conserve space, we do not report these estimates here, but rather point out that the PDs with independent defaults are *higher* than those based on correlated ones.

Intuitively, this is best understood in the context of an example with two events (A and B). From fundamental probability theory we know that the union of events A and B, that is, A, and/or B occur, is defined as:

$$\begin{aligned} P(A \cup B) &= P(A) + P(B) - P(A \cap B) \\ &= P(A) + P(B) - P(A|B)P(B). \end{aligned} \tag{13}$$

When events A and B are independent, $P(A\,|\,B) = P(A)$, so that the probability of the union becomes:

$$\begin{aligned} P(A \cup B) &= P(A) + P(B) - P(A)\,P(B) \\ &= P(A) + P(B)[1 - P(A)], \end{aligned} \tag{14}$$

while for the case when the events are perfectly "correlated", or *A* is predictable with certainty once *B* has occurred ($\mathrm{P(A|B)} = 1$), we obtain $\mathrm{P(A|B)P(B)} = \mathrm{P(B)}$, so that the relation in (13) becomes:

$$\begin{aligned} P(A \cup B) &= P(A) + P(B) - P(B) \\ &= P(A). \end{aligned} \tag{15}$$

Thus, unless $P(B)[1 - P(A)] = 0$ (when either $P(B) = 0$ or $P(A) = 1$) the probability of the union of the events is always going to be larger under the independent scenario than under the perfectly correlated one.

Note here also that, although we have used the Copula linking function to compute the joint cdf of no bank defaulting, one can always build up the joint cdf from the product of the conditionals (and an initial marginal) as:

$$P(A \cap B \cap C \cap D) = P(A|B \cap C \cap D)P(B|C \cap D)P(C|D)P(D). \tag{16}$$

To do this, all that is needed from the Merton model is one (marginal) cdf of not defaulting (available from the individual bank PDs), and some statements about the conditional probabilities, i.e., $P(A|B \cap C \cap D)$, $P(B|C \cap D)$, and $P(C|D)$ above in (16). Banking supervisors and/or specialists may have a fairly strong view on what these conditional probabilities should look like, based on, for instance, their institutional knowledge. As an example of how this can be done, if one knows that bank *D* did not default, then one might be confident to say that bank *C* will default only with a low probability of 3 per cent. Similarly, if both *C* and *D* did not default, then the probability of *B* defaulting (given *C* and *D* did not default) is even smaller at 0.5 per cent, etc. The joint cdf in (15) can then be built up iteratively as the product by starting from the marginal cdf taken from the Merton model PDs, and (subjective) assumptions on the conditional cdfs.

Conclusion

We use a standard Merton model to estimate the probability of default for the four large Swedish banks. Based on these PDs and the historical correlation between the banks' equity returns, we estimate the probability of a banking crisis at different levels of capital to total assets, where a banking crisis is defined as the probability of at least one of the four major banks failing. Our model estimates show that additional equity reduces the probability of a banking crisis. However, the reduction in the probability of a crisis that follows from an increase in equity declines quite rapidly at higher capital levels. The reason for this is that the amount of tail risk is modest as a result of both the assumptions of the model and the scenario based analysis that we implement.

While our results serve as a benchmark, we wish to emphasise that this approach has several drawbacks. In particular, the estimated PDs are sensitive to the estimate of the volatility of the banks' assets. Although we proxy the time-varying nature of volatility by using a 1-year *forward* rolling window to capture the actual volatility realized over the default horizon of one year that we consider, performing a scenarios based analysis for different levels of capital to total assets and the historically observed asset value volatilities does not capture the fact that bank losses are generally fat tailed distributed and that they cluster. Another drawback is that we cannot capture the high level of equity volatility experienced during the 1990s housing crisis due to the lack of accounting and equity price data going back that far which are needed to back out asset value volatilities. Both of these limitations are likely to lead us to underestimate the probability of a banking crisis in the Swedish banking system.

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Appendix E - A reduced form model for assessing the probability of a banking crisis

Paolo Giordani

Introduction

In order to evaluate the effects of higher capital requirements, we need to estimate their impact on the probability of default of Swedish banks. The most common approach is to use some version of the Merton model, which does not require knowledge of the value of assets, as in Appendix D.

Here, we complement Appendix D by opting for a different approach. We use a long time series for credit losses in the Swedish banking system and model such losses directly rather than inferring them via stock market prices, as in the Merton model.

We base our analysis on a historical dataset (Hortlund, 2005; 2008) covering the period 1870–2008 for a yearly aggregate of Swedish banks, reporting: a) credit losses, b) total assets, and c) capital. Since the historical dataset only gives aggregate data, our analysis will make statements about the aggregate of all Swedish banks, in effect treating the entire system as one large bank. As a result, the default probabilities will be lower than if we had data on individual banks and defined a default event for one major bank in default.

The dataset includes credit losses but not profits or overall return on equity. To calculate profits after credit losses, we assume that performing loans earn a net margin of 0.75 per cent. In the historical dataset this would correspond to an average return on assets, after credit losses, of 0.4 per cent, which, at current leverage ratios (capital to assets of 4–5 per cent) translates into a return on equity of 8–10 per cent on average (including periods of high losses). Outside the three crisis periods (see Chart 1), credit losses are smaller and the corresponding return on equity at current leverage ratios is 12–17 per cent. Returns on assets in any given year are thus computed as:

$$Return\ on\ assets = L + 0.0075\,(1 + L)$$

$$L = -\frac{Credit\ \ Losses}{Assets}$$

To compute a probability of default as a function of the capital ratio (equity over assets), we then require a definition of what constitutes default, and a statistical model for credit losses. Equity here is assumed to be capital to total (i.e. non-risk-weighted) assets, so no model of risk weights is needed.

Default is defined as capital over assets falling behind a given threshold. For example, if the threshold is 0 (so that default requires the entire capital to be wiped out), default requires

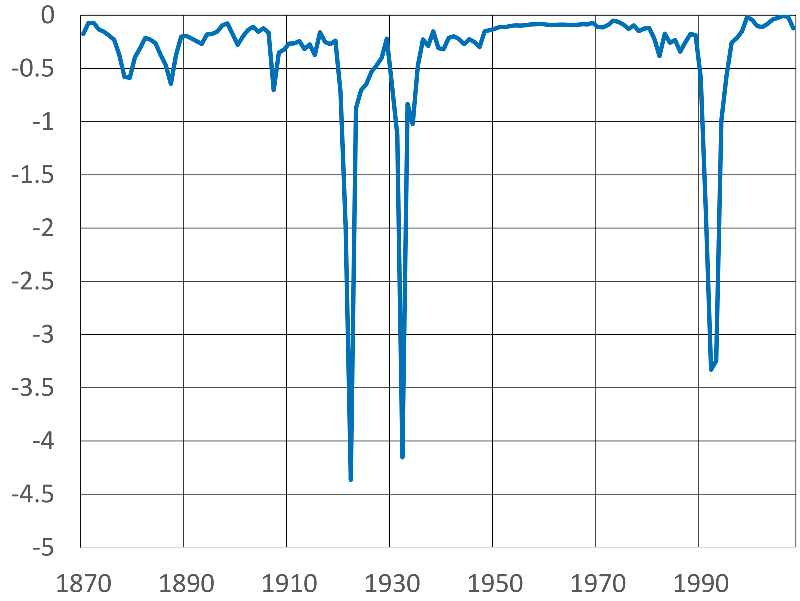
$$Capital\ ratio + Return\ on\ assets < 0$$

We consider three critical levels: 0, 1.5, and 3 per cent, as discussed in the main body of this staff memo.

A statistical model for credit losses

Yearly data on credit losses are shown in Chart 1 below. Losses are very small in most years, and very large in three historical episodes. After 1950, losses in most years are extremely small, whereas during the crisis of the early 1990s they are comparable to losses in the 1920s.

Chart 1. Historical losses/assets, 1 year
Per cent



Source: Hortlund (2005; 2008)

The empirical distribution is challenging to fit for standard statistical distributions. We therefore make a non-standard choice and fit a half-t distribution. This is simply a student-t distribution with zero density for positive values. The probability density function is

$$P(x) = 2 \cdot t(x, 0, s^2, v) \; for \; x < 0 \; (\text{and } P(x) = 0 \; for \; x > 0),$$

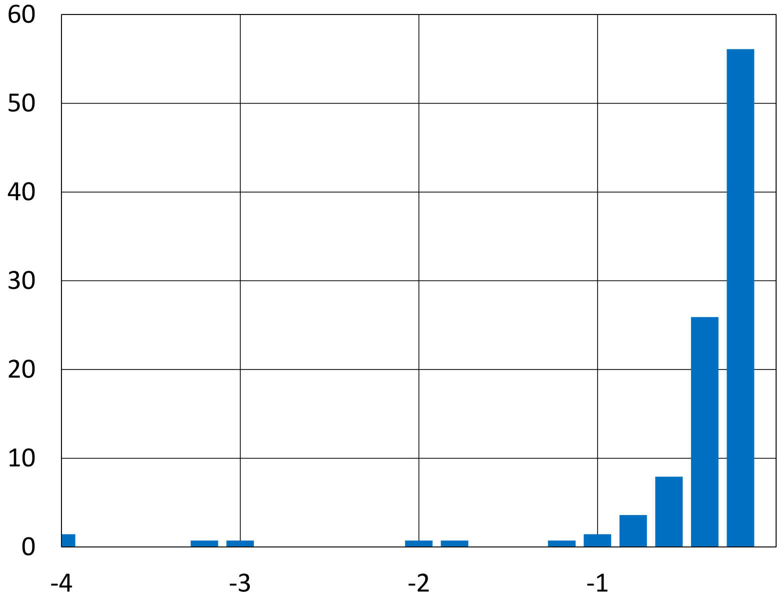
where $t(x, 0, s^2, v)$ is a student-t distribution with mean zero, degrees of freedom v and dispersion s^2. The density is multiplied by two so that it integrates to one. The half-normal and half-t distribution is sometimes used as a prior in Bayesian analysis. We are not aware of any application of a half-t to model an actual time series, but for the series of losses shown in Chart 1 it may be hard to improve on it (see Chart 2). A more commonly employed alternative may have been a Generalized Pareto distribution, or a Generalized Hyperbolic distribution (see McNeil et al. 2015), which are strictly non-negative and also have semi-fat tails. In our particular dataset, visualised in Chart 1, these distributions do not perform nearly as well as a half-t (in log-likelihood), perhaps due to difficulty in capturing the many observations at near-zero values.

The model is estimated with Bayesian methods using fairly disperse priors on $\log(s^2)$ and $\log(v)$, which imply a lower bound of 1 for v. Maximum-likelihood estimates give very similar results, except for extremely low probability events (losses much larger than those observed in sample), where even small changes in the prior affect the results and the averaging over draws of $\log(v)$, as opposed to conditioning on one value as in maximum likelihood, resulting in fatter tails.

Results for a one-year horizon

Chart 2 shows a histogram of losses (the same data that are shown as a time series in Chart 1) in the first panel, and Chart 3 shows the corresponding histogram (using the same intervals for the bins as in Chart 2) produced by the estimated model. The posterior distribution of the degrees of freedom has a mean of 2, and almost 10 per cent of the draws are between 1 and 1.5. This generates an extremely fat left tail, and yet the model if anything falls short of matching the largest losses in the data. A Gaussian distribution or even a symmetric student-t would be inadequate in our case. While the variance of a student-t distribution is not defined unless ν is larger than 2, the mean absolute error is defined for ν larger than 1. At $\nu = 1$ the student-t distribution is equivalent to the Cauchy distribution.

Chart 2. Empirical histogram of losses over assets (horizon 1 year). Losses are in per cent.
Per cent (frequency)



Source: Hortlund (2005; 2008)

Chart 3. Model-implied histogram of losses over assets (horizon 1 year). Losses are in per cent.
Per cent (frequency)

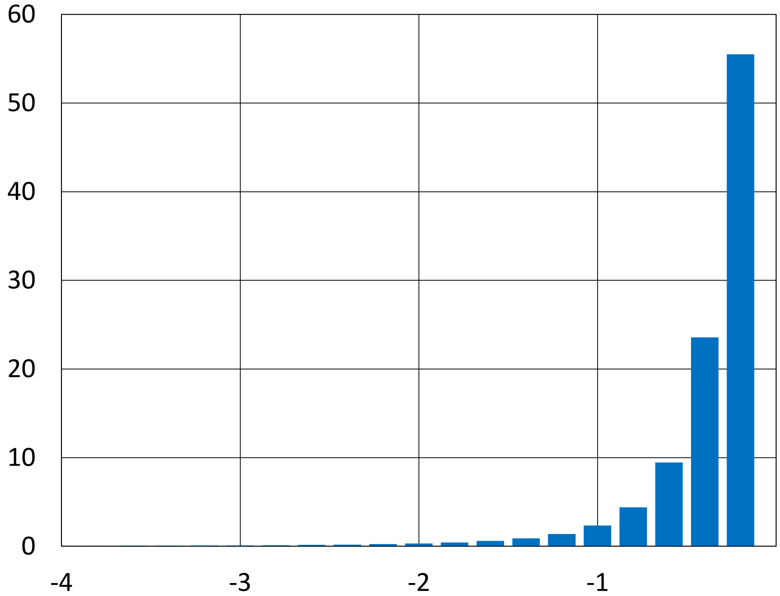


Chart 4 shows the entire distribution implied by the model in the first panel, and Chart 5 zooms in on the tail. For very large losses, the density approaches zero very slowly, showing near power-law behaviour as a consequence of very low degrees of freedom. Importantly, this implies that, unlike a Gaussian distribution, this model can generate losses substantially larger than those observed in sample.

Chart 4. Density of the estimated half-t distribution (horizon 1 year)

Density, normalized to 1 at x = 0

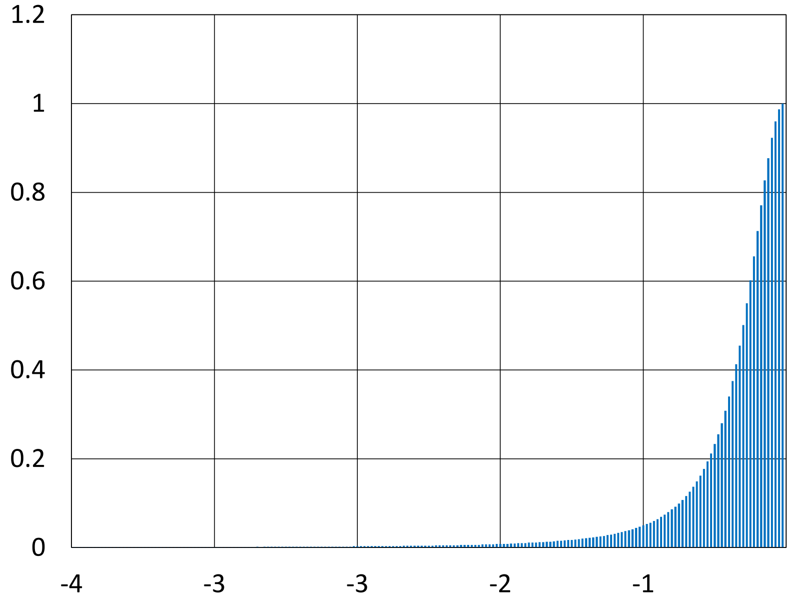
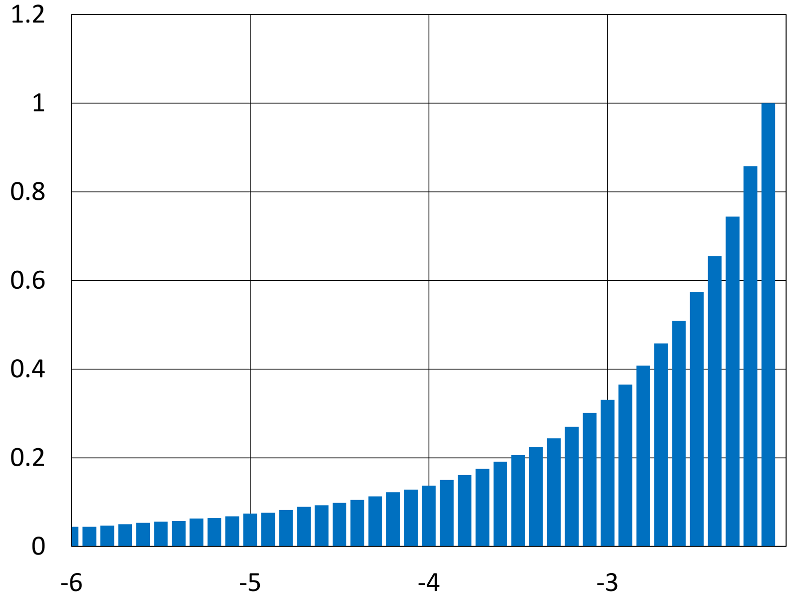


Chart 5. Density of the estimated half-t distribution (horizon 1 year), $x < -2$

Density, normalised to 1 at x = -2



Charts 6–8 plot default probabilities as a function of starting values of the capital/assets ratio, for three definitions of default, corresponding to capital over assets below 0, 1.5 per cent and 3 per cent respectively.

Chart 6. Probabilities of default as a function of the capital ratio, default at 0 per cent

Probability of default

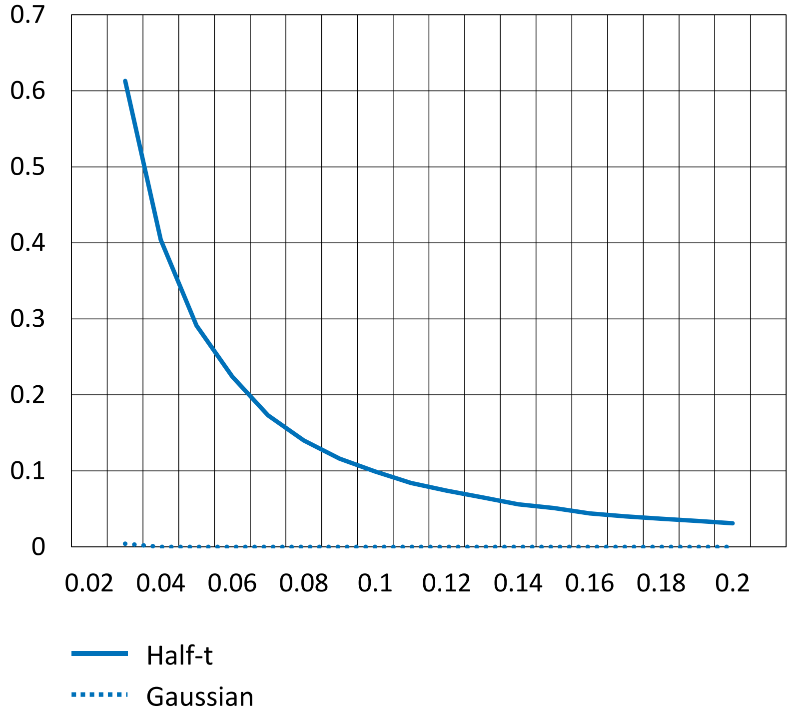


Chart 7. Probabilities of default as a function of the capital ratio, default at 1.5 per cent

Probability of default

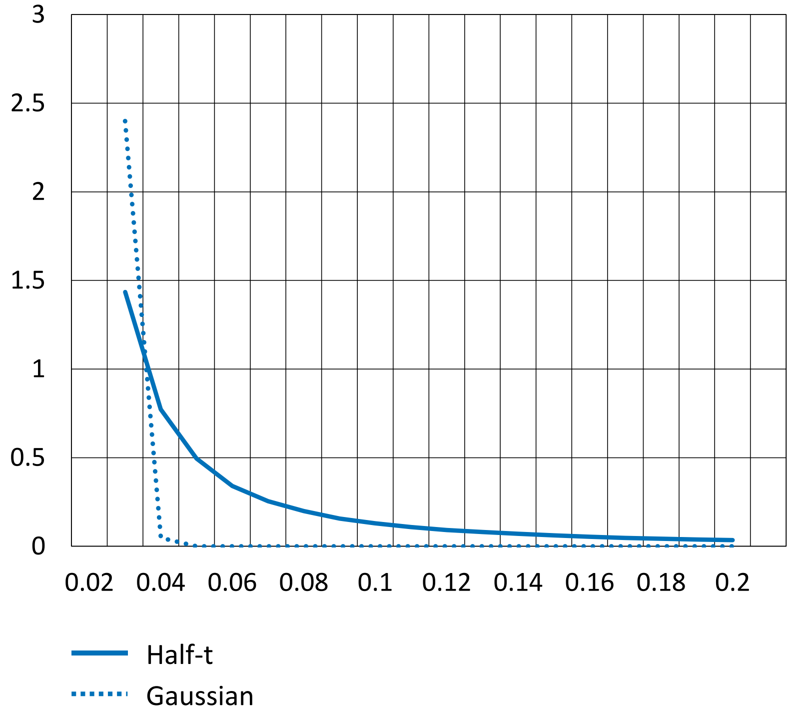
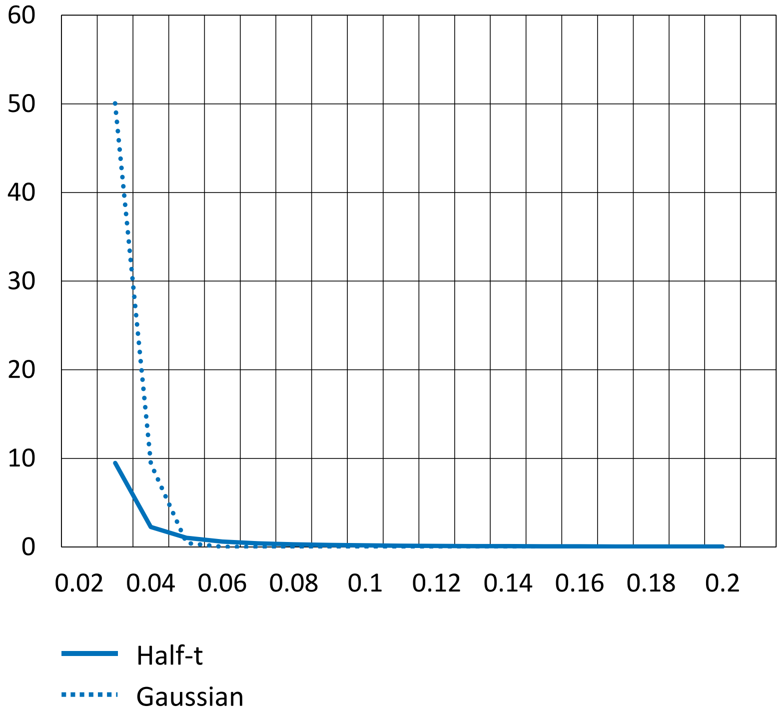


Chart 8. Probabilities of default as a function of the capital ratio, default at 3 per cent
Probability of default



Referring to Charts 6–8, the default probabilities implied by the half-t distribution decrease smoothly, whereas those implied by the Gaussian (a symmetric and thin-tailed distribution), decrease sharply. As a consequence, compared to a Gaussian, conclusions on default probabilities are less sensitive to modest changes in the estimated mean and variance.

Results for a three-year horizon

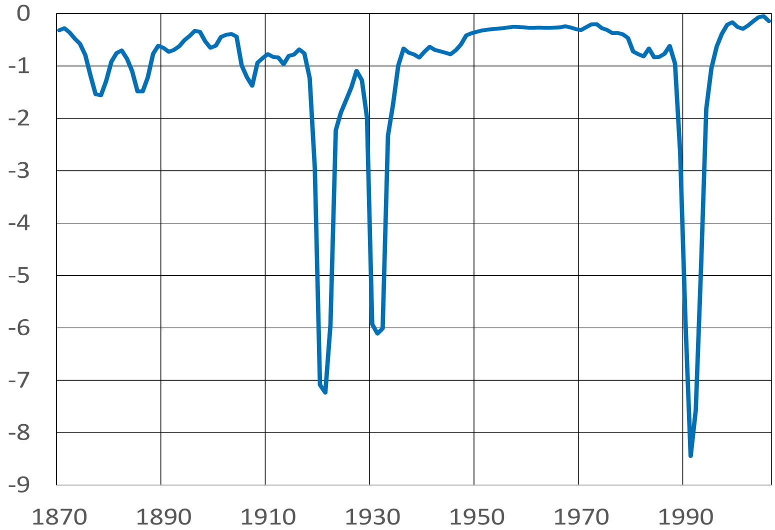
The model at a one-year horizon captures the extremely long tail in bank losses in any given year, but a one-year horizon is almost certainly too short considering that in the data large losses cluster, so that a bad year tends to be followed by another bad year. It is therefore possible for a bank's equity to be wiped out gradually in the course of a few years rather than in a single year. To work with a multi-year horizon we require further assumptions both in defining defaults and for the statistical model.

To define defaults, we assume that banks cannot raise equity within each three-year window, but must rely entirely on equity available at the beginning of the period and on earnings. We also assume that the profit margin on performing loans is constant at 75 basis points. During the crisis of the early 90s, Swedish banks were in fact able to substantially increase their margins, particularly at the expense of households and companies with floating-rate loans. It is not obvious whether banks would be able to repeat this behaviour to the same extent today (Sweden joined the European Union in 1995, after the crisis). Even if they were able to boost margins, the negative macroeconomic and social implications may be sizable.

In terms of modelling, one option would be to build a dynamic model so that yearly losses are not independent. A main advantage of this approach is that we could define a default if an established lower bound for capital over assets is breached *at any point* during the period (say three years). An obvious disadvantage is the need to introduce further modelling assumptions and parameters. We opt instead for a direct modelling approach, in which cumulative losses over equity are modelled directly at the horizon of interest. This requires less additional assumptions, but it does have the drawback that we can only make statements concerning outcomes at the end of the multi-year period. The probabilities of default produced by a direct modelling approach should therefore be interpreted as a lower bound, since they exclude the possibility of banks being in default at some point during the time horizon of interest but not at the end of it. Chart 9 shows the cumulative three-year losses. The distribution is just as asymmetric as at the one-year horizon, if not more.

Chart 9. Cumulative three-year losses over equity

Per cent



Source: Hortlund (2005;2008)

The degrees of freedom parameter is again around two (mean value), producing a thick and gently sloping left tail similar to the one shown in Charts 3–4.

Charts 10–12 show the probability of default at the three-year horizon, which should be interpreted as the probability of banks not having sufficient capital at the end of the three-year period. Charts 13–15 show the same data without a comparison with the Gaussian distribution. The main feature of interest is that the default probabilities implied by a Gaussian can be high at low capital ratios (recall that the Gaussian is symmetric, centred at the average loss), but drop very sharply, whereas the half-t produces gently sloping default probabilities, never particularly high in any given period, but never quite hitting zero either, so that higher capital ratios continually reduce the probability of default.

Chart 10. Probabilities of default as a function of the capital ratio, default at 0 per cent (3-year horizon)

Probability of default

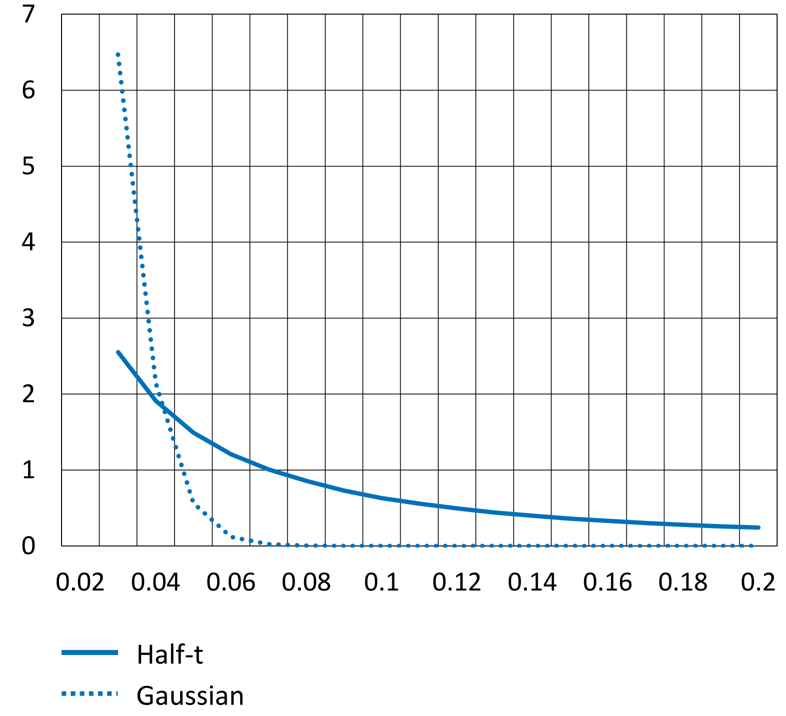


Chart 11. Probabilities of default as a function of the capital ratio, default at 1.5 per cent (3-year horizon)

Probability of default.

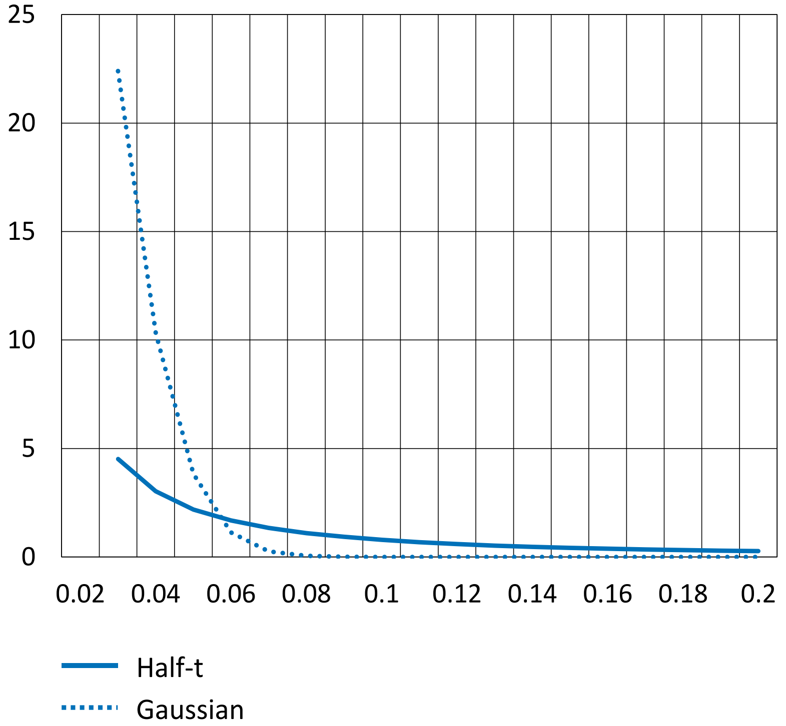


Chart 12. Probabilities of default as a function of the capital ratio, default at 3 per cent (3-year horizon)
Probability of default

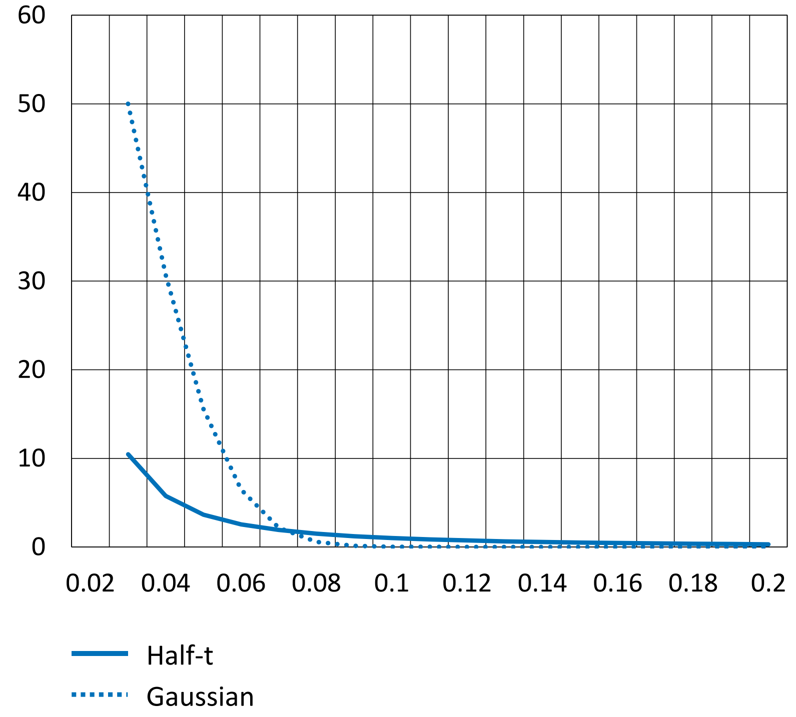


Chart 13. Probabilities of default as a function of the capital ratio, default at 0 per cent (3-year horizon)
Probability of default

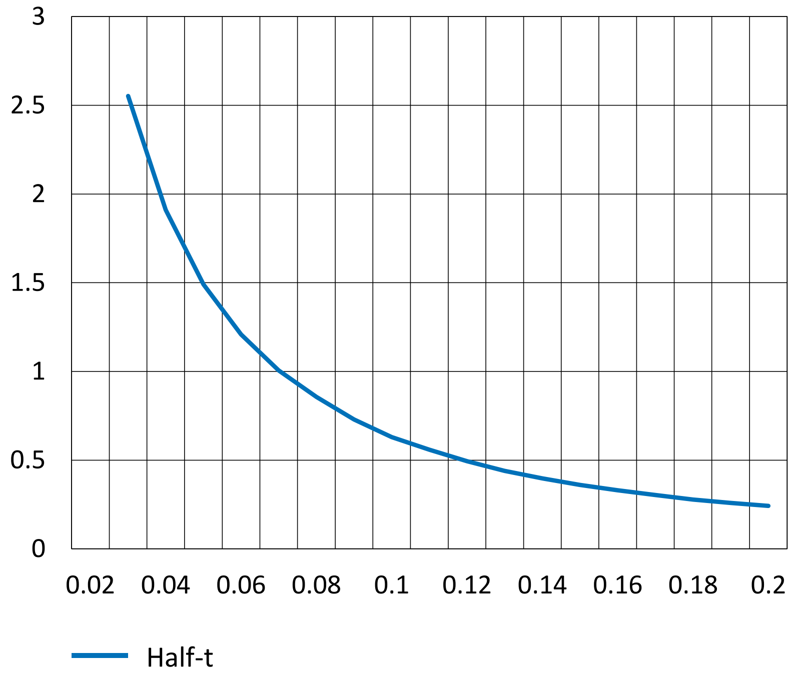


Chart 14. Probabilities of default as a function of the capital ratio, default at 1.5 per cent (3-year horizon)

Probability of default

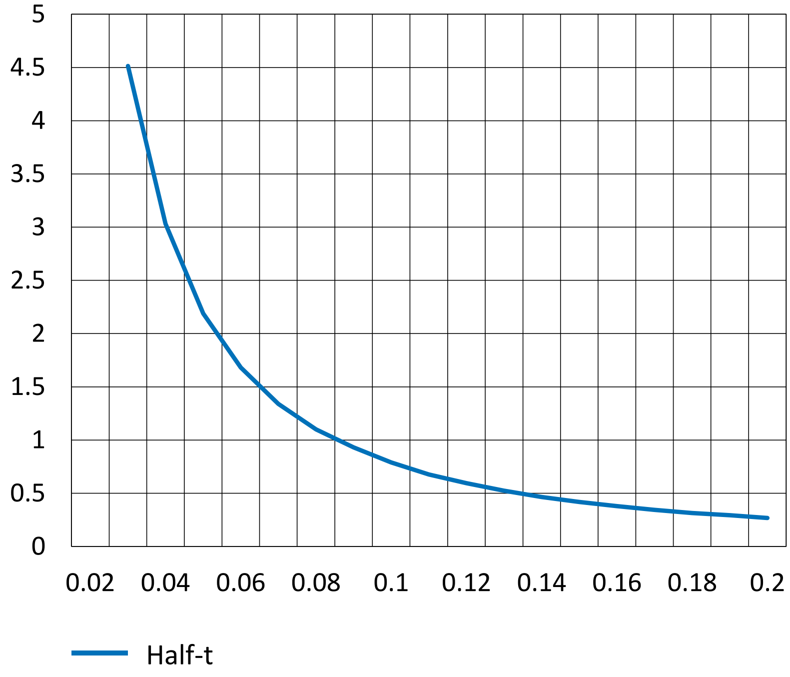
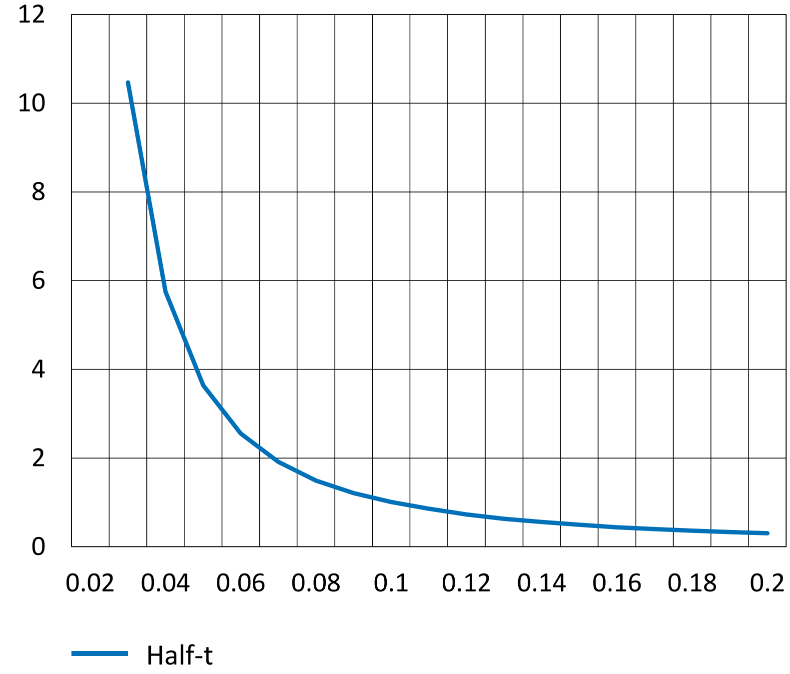


Chart 15. Probabilities of default as a function of the capital ratio, default at 3 per cent (3-year horizon)

Probability of default



An advantage of replacing a Gaussian or a similarly thin-tailed symmetric distribution with a less unrealistic alternative is that results are more robust to variations in assumptions and sample. Charts 5–7 and Charts 10–12 show how the default probabilities implied by the Gaussian are much more sensitive to the threshold used to define default. From the same Charts we can safely imply that the half-t will also be less sensitive to the precise definition of the capital ratio (for example to different risk weights).

Conclusion

We have presented a simple model in which losses for the Swedish banking system are modelled directly rather than being inferred from stock prices. The most salient feature of the historical data, which cover the period from 1870 to 2008, is that long periods of small losses are interrupted by shorter periods of very large losses. A half-t distribution with very low degrees of freedom does a much better job than a Gaussian at reproducing these features of the data, and yet even this model struggles to match the largest losses in the data.

In interpreting the results it is also useful to keep in mind that computations of low probability events necessarily rely on assumptions more heavily than computations of higher probability events, and therefore that the further out in the tail (i.e. the smaller the probability), the more results are driven by assumptions (in our case, by the choice of a half-t distribution) and by sampling error.

The main conclusion of our exercise is that, compared to a Gaussian distribution, a more accurate statistical model of bank losses lead to substantially different conclusions regarding the effects of different capital ratios. Using a half-t distribution typically (though not always) results in smaller probabilities of hitting a critical value when banks are very highly levered. Technically, this reflects the properties of highly asymmetric and fat-tailed distributions (of which the half-t is an example), in which small deviations from the mode are more frequent than in the Gaussian. Intuitively, this means that even a dangerously levered bank may survive without a critical event for decades. On the other hand, the probabilities of critical events fall off much more gently (as the capital ratio is increased) using a half-t distribution, reflecting a larger probability of big losses compared to the Gaussian. Hence increasing equity continues to meaningfully reduce the probability of default at capital ratios for which a Gaussian implies (incorrectly) a near-zero default probability. Because probabilities of critical events obtained under a Gaussian assumption fall so rapidly with the capital ratio, they are also more sensitive to assumptions about the appropriate threshold for a critical event and to parameter estimates, implying that conclusions draws from Gaussian assumptions in actual applications are likely to prove very fragile to differences between in-sample and out-of-sample data.

References

Hortlund, Per, 2005, "Studies on Swedish Banking 1870–2001," PhD dissertation, Stockholm School of Economics. The data was later extended to 2008 by the author.

McNeil, Alexander, Frey, Rüdiger, and Embrechts, Paul, 2015, "Quantitative Risk Management: Concepts, Techniques and Tools," Princeton University Press.

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