Far out in the tails – The historical distributions of macro-financial risk factors in Denmark[1]

Kim Abildgren
Danmarks Nationalbank, mail: kpa@nationalbanken.dk

The macro stress tests used by the authorities in many countries prior to the most recent financial crisis did not pay sufficient attention to low-probability but high-consequence scenarios. Economic history is rich on extreme events which we illustrate by taking a closer look at the frequency and magnitude of extreme events in the economic history of Denmark. We suggest using distributions of macro-financial risk factors based on long-span historical time series as inspiration in relation to low-probability scenarios in macro stress tests.

1. Introduction

Since the outbreak of the most recent international financial crisis, there has been a growing academic research interest in macro stress tests of the financial system. Macro stress tests are designed to assess the robustness of the financial system against adverse shocks to the macro economy, and they usually serve as the basis for discussions and actions on potential threats to financial stability and as a framework for communicating such risks. There is therefore also a huge focus on

1. The author is grateful to the editor of this journal and two anonymous referees, whose insightful and constructive comments and suggestions have been significant in helping to shape and improve the article in the review process. Furthermore, the author wishes to thank colleagues from Danmarks Nationalbank and participants at the 2014 Koldingfjord Conference of the Danish Economic Society for useful comments on earlier drafts of this article. Views and conclusions expressed in the article are those of the author and do not necessarily represent those of Danmarks Nationalbank. The author alone is responsible for any remaining errors.

refining and expanding the range of approaches used for macro stress testing among financial regulators and central banks. Better stress tests have the potential to improve the basis for assessment of financial stability and the need for macro-prudential regulations.

With hindsight, it has become clear that the macro stress tests used by the authorities in many countries prior to the most recent financial crisis did not pay sufficient attention to low-probability but high-consequence scenarios (Alfaro and Drehmann, 2009; Chelluboina *et al*., 2014). This was also the case in Denmark. In 2012, the Danish Ministry of Business and Growth established a Committee of experts to review the causes of the recent financial crisis. In the report from the Committee (the so-called "Rangvid report"), it was noted that:

"Experience from the financial crisis has exposed the limitations of the stress tests used by the authorities. These limitations were expressed by the models' failure to identify the financial sector's general vulnerability in the run-up to the financial crisis" (page 19 in Danish Ministry of Business and Growth, 2013).

Furthermore, the Committee recommended that:

"... the models should also be further improved in the future via new knowledge and a focus on including low-probability but high-consequence scenarios ..." (page 20 in Danish Ministry of Business and Growth, 2013).

In the paper at hand, we outline the strengths and weaknesses of the usual design of macro stress tests. We suggest using distributions of macro-financial risk factors based on long-span historical time series as inspiration in relation to low-probability scenarios. Economic history is rich on extreme events, which we illustrate by taking a closer look at the frequency and magnitude of extreme events in the economic history of Denmark, in some cases based on time series back to the late 1600s. We focus on the distributions of a range of key macro-financial risk factors that are commonly believed to be important drivers of credit risks and market risks faced by financial institutions. The distributions of macro-financial risk factors based on long-span historical time series remind us that extreme events might occur more often than we would think, if we only relied on an historical experiences from relative short data samples.

However, all approaches usually have pros and cons. We discuss a number of challenges and limitations that are related to the use of long-span historical time series as inspiration in relation to low-probability scenarios.

2. The design of macro stress tests

Typically, macro stress testing implies the construction of scenarios for hypothetical developments with adverse shocks to the macro economy and an evaluation of the potential loan loss provisions *etc*. in the financial system as a whole or individual financial institutions in such scenarios. The purpose of macro stress tests is to throw light on the financial system's resilience to rare but plausible shocks and thereby uncover key vulnerabilities and systemic risks in the financial sector (Sorge and Virolainen, 2006; Foglia, 2009; Gaglianone and Schechtman, 2012)

Central banks and supervisory authorities have a number of different approaches to macro stress testing of the financial system. A basic distinction is often made between "top-down" and "bottom-up" stress testing. In top-down stress tests, the authorities perform all calculations, while bottom-up stress tests are performed in co-operation with those financial institutions whose resilience are to be tested. Consequently, in top-down stress tests, loan impairment charges *etc*. in a stress scenarios are calculated using the authorities' macro stress testing model, while the calculations in bottom-up stress tests are based on the models of the individual financial institution using the scenarios outlined by the authorities (Abildgren and Damgaard, 2012). In principle the bottom-up approach allows for the use of different scenarios for different banks, for instance differentiated by the banks' business model or geographical location (Schuermann, 2014).

Borio *et al*. (2014) outlines four key elements in a macro stress testing framework: Risk exposures, scenario, model and outcome.

The main *risk exposures* in focus in macro stress tests are typically the financial systems' exposure to credit risk and market risk. Credit risk is the risk of losses due to the counterparties' insufficient ability to meet their payment obligations, whereas market risk is the risk of losses as a consequence of fluctuations in prices on financial assets such as stock prices, bond prices or exchange rates. The current balance-sheet positions of financial institutions are thus a key starting point in any macro stress test.

Another key element in a macro stress test is the construction of a *scenario* for a hypothetical development with adverse exogenous shocks to the economy. Since the aim of a stress test usually is to throw light on the robustness of the financial system, the scenario should reflect possible, but not very probable, large shocks to the economy.

A third key element in a macro stress test is the *model* used to calculate the impact of the shocks on the macro economy and the income and balance-sheet positions of the financial institutions. Such models can be divided into two main approaches: The simultaneous approach and the satellite approach (Abildgren and Damgaard, 2012).

The simultaneous approach provides for a simultaneous calculation of the impact of the shocks on the macro economy and the financial sector. This approach

makes use of a simultaneous model that covers not only the interactions among macroeconomic variables such as economic growth, inflation, interest rates and house prices, but also contains a financial sector in order to capture both the pass-through from the macro economy to the financial sector and the feedback effects from the financial sector to the macro economy via financial frictions. Financial frictions could for instance be binding collateral constraints of the borrowers due to declines in asset prices or capital constraints on the lending-supply capacity of the banking system. The simultaneous model may be a relatively small vector autoregressive (VAR) model of the aggregate economy or a larger econometric model with structural relations describing the interaction between the banking system and the rest of the economy.

The satellite approach splits the calculation process in two steps. In the first step, the impact of the shocks on the macro economy is calculated via a macroeconomic model. In the second step the impact on the financial system is assessed via a satellite model with modules for credit risk, market risk *etc*. The strength of satellite models is their less complex architecture that allows for a more detailed level of calculation of the impacts on the profit and loss accounts and the balance sheets of financial institutions. However, the satellite approach does not automatically take the feedback effects from the financial sector to the macro economy into account as is the case in the less detailed simultaneous approach.

The final key element in a macro stress testing framework is the *outcome* of the scenario, for instance the level of solvency of the banking system as a whole or of individual banking institutions.

The main challenges in the design and implementation of macro stress tests are usually related to the scenario and the model.

As mentioned the *scenario* should reflect realistic, but not very probable, large shocks to the economy. Typically scenarios are either based on purely hypothetical shocks or based on past experiences, either by choosing specific historical episodes or by drawing shocks from the tails of historical distributions of relevant risk factors (Borio *et al*., 2014). Drawing shocks from the tails of distributions makes it under the assumption of fixed distributions in principle possible to evaluate the likelihood of the shocks whereas the probability of purely hypothetical shocks can not be assessed.

A lesson from the period prior to the recent financial crisis is that the construction of purely hypothetical shocks that are sufficiently "hard" to match the observed reality during severe financial crises is not so easy as it may sound. During seemingly tranquil times, it can be a challenging communication task to get "hard" regime-switch scenarios accepted as realistic and probable, cf. also the "this time is different" syndrome described in Reinhart and Rogoff (2009).

Shocks based on past experiences are often derived from easily obtainable but fairly short historical data sets covering at best the most recent decades or so. It might be easier to communicate scenarios based on the most recent experiences

as realistic and probable – it has happened before as most can remember. However, Haldane (2009) and Abildgren (2014) have recently highlighted the so-called "small-sample problem" that might be the result from the use of fairly short historical data sets for such an exercise. Relying on short historical data sets implies a risk of underestimating the frequency and magnitude of extreme events related to currency crises, changes of monetary regimes, banking crises, debt crises, severe stock-market collapses, wars, episodes of high inflation or hyperinflation *etc*.

In the article at hand, we suggest using shocks drawn from distributions of macro-financial risk factors based on long-span historical time series as the basis for low-probability scenarios. Economic history is rich on extreme events which we illustrate in Section 3 by taking a closer look at the frequency and magnitude of extreme events in the economic history of Denmark. Long-span historical time series can also be useful if one prefers to use a specific historical episode as a scenario instead of drawing shocks from the tails of historical distributions of risk factors. Varotto (2012) has recently suggested to use the Great Depression of the interwar period as a "worst case" scenario in macro stress tests.

The *model* represents another considerable challenge in relation to macro stress testing. The dynamic interactions between the financial sector and the real economy are rich and complicated. Especially the feedback effects from the banking sector to the real economy are difficult to quantify and are therefore often left out as mentioned above in relation to the satellite modelling approach.

Furthermore, economic models are usually designed to capture average rather than extreme outcomes, and the correlation between various macro-financial risk factors might be subject to tail dependence. The economy might behave fundamentally different in times of crisis than in tranquil periods, so estimated statistical relationships might break down during crises and not be valid as the basis for calculating the impacts of shocks in "hard" stress scenarios (Asai *et al*., 2013).

Traditional economic models are often based on the assumption of linear relationships that may be reasonable when shocks to the economy are small. However, the transmission from the macroeconomic development to the health of the financial system is not necessarily linear when the shocks to the economy are large. This problem is often described as "non-linearities" in the literature (Billio *et al*., 2013). Non-linearities might e.g. emerge during a financial crisis due to fire sales of assets, illiquid financial markets or collateral constraints that suddenly become binding. There might also be non-linearities in the repayment capability of the banks' customers. The latter might e.g. reflect that the wealth status of firms in financial distress and unemployed households deteriorates in step with the length of a financial crisis. Non-linearities might also be a result of growing perceived uncertainty about the future economic outlook among households and firms brought about by the financial crisis. As noted by e.g. Borio *et al*. (2014), non-linearities are still not well captured by traditional economic models used for macro stress tests.

In the article at hand we suggest using simple static sensitivity analyses based on experiences from long-span historical time series as a supplement to model-based macro stress tests. In a sensitivity analysis one assesses how a large shock to a single macro-financial risk factor in isolation affects the resilience of the financial system, all other things being equal, and the historical distribution allows for an evaluation of the likelihood of such a shock. Simple sensitivity analysis can often be based directly on risk exposures derived from the balance-sheet statements and risk reports of financial institutions without the need of a macroeconomic model.

In the wake of the recent financial crisis a number of reports and studies have considered the scope for and limitations of the use of macro stress tests. In the "Rangvid report" it was noted that:

"... the Committee finds it important to emphasize that results from stress tests do not bring all matters in individual banks to light, and stress test results should therefore not be overinterpreted" (page 20 in Danish Ministry of Business and Growth, 2013).

Furthermore, Borio *et al*., *op. cit*., note that:

"... given current technology, macro stress tests are ill-suited as early warning devices" (page 3 in Borio *et al*., 2014).

but that:

"as long as properly designed, stress tests can be quite effective as crisis management and resolution tools" (page 3 in Borio *et al*., 2014).

The overall assessment seems thus to be that macro stress tests can be useful tools but that they cannot stand alone in a comprehensive evaluation of the robustness of the financial system against adverse shocks to the macro economy.

Following the recent financial crisis, focus among central banks in many countries has therefore also been concentrated on developing additional frameworks, indicators and models that can be useful as supplementary analytical tools for macro-prudential oversight. This work includes for instance early warning systems for systemic financial instability and widespread macroeconomic imbalances, systemic risk indicators and measures of the degree of interconnectedness among financial institutions suitable for nowcasting systemic fragility and contagion risks, models designed to capture liquidity and funding risks, *etc*. (ESCB Heads of Research, 2014).

3. The distributions of macro-financial risk factors in Denmark based on long-span historical time series

Economic history is rich on extreme events which we illustrate in this section by taking a closer look at the frequency and magnitude of extreme events in the economic history of Denmark, in some cases based on time series back to the late 1600s. We focus on the distributions of a range of key macro-financial risk factors that are commonly believed to be important drivers of credit risks and market risks faced by financial institutions in many countries (Marcucci and Quagliariello, 2008; Dovern *et al*., 2010; Ali and Daly, 2010; Ahmad and Bashir, 2013; Castro, 2013).

The sources and methods used for the construction of the data sets are documented in a background paper (Abildgren, 2013). The background paper also includes tables with detailed information on the development in the macro-financial risk factors sorted by size of the annual or quarterly changes in the risk factors.

We will also comment on the size of the changes in the key macro-financial risk factors during both the most recent and earlier financial crisis in Denmark, cf. Table 1 for a summary of banking crises in Danish economic history since 1857.

In the literature, several different approaches have been used to identify periods of banking crises. Reinhart and Rogoff (2009) delimit banking crises to situations in which the government has intervened in various ways. Bordo *et al*. (2001) classify banking crises as situations in which a large part of the banking sector's capital base is undermined, and de Haan *et al*. (2015) make use of an index of money market pressure. Different approaches have also been used to pinpoint the start and end times of banking crises. For example, some studies define the start of a banking crisis based on the timing of a significant drop in the stock indices for banks, the timing of a substantial fall in bank deposits or the timing of government intervention to support financial stability. In some studies, the end time of a banking crisis is determined as the time when output growth is back at the pre-crisis trend level or as the time when government support measures expire.

Using the above methods of determination, it may often be difficult or even impossible to determine exactly when a banking crisis begins or ends. For example, there is the question of what is "significant" or "substantial". Furthermore, a banking crisis may have started well before the government intervenes. There may also be cases in which a crisis becomes critical after government intervention (or after the first intervention). Ultimately, the identification and delineation of periods of banking crises will always have elements of subjectivity and judgement, and often an "expert opinion" is also seen as a method of delineation (Abildgren *et al*., 2011). The definition chosen in the article at hand is based on an "expert opinion" approach by selecting those periods characterised as banking crises in Danmarks Nationalbank's "Monetary History of Denmark" in six volumes.

Table 1: Banking crises in Danish economic history since 1857

Crisis	Brief description	Extraordinary measures by the authorities	International dimension?
The Monetary Crisis 1857-1858	A number of deposit banks and trading houses dependent on foreign financing experienced liquidity problems.	The government established a "Temporary Loan Fund", which provided loans to deposit banks, trading houses *etc*.	International liquidity crisis that spread from the US to Europe.
The Savings Bank Crisis 1876-1878	Several savings banks and a few commercial banks came into crisis.	The Nationalbank had to provide extraordinary loans to a few deposit banks.	In 1873 the global economy was hit by a prolonged recession.
The Liquidity Crisis 1885	The banking sector's liquidity came under pressure during a wave of bankruptcies among non-financial firms.	Liberal lending policy by the Nationalbank.	No.
The Construction and Banking Crisis 1907-1909	Several medium-sized commercial banks experienced difficulties after a building boom in the Copenhagen area.	The government, the Nationalbank and a number of large private banks established a Banking Committee with a view to providing guarantees for depositors and other creditors in crisis-stricken commercial banks. Denmark's largest savings bank was reconstructed with government help after an incidence of serious fraud.	The US banking crisis in 1907 impeded international financing.
The Interwar Banking Crisis 1920-1933	A large number of Danish commercial banks, including the five largest, experienced difficulties.	Several large commercial banks, including Scandinavia's largest bank – Landmandsbanken – received capital and/or liquidity support from the government and the Nationalbank.	The late 1920s and the early 1930s were characterised by financial, banking and currency crises in many countries, cf. the US stock market crash in 1929 and the collapse of the international gold standard system in 1931.
The Kronebank Crisis 1984-1985	Denmark's seventh largest commercial bank, Kronebanken, experienced difficulties.	Danmarks Nationalbank and a number of large commercial banks provided a guarantee aimed at depositors and other creditors in Kronebanken.	No.
The seven-year slump 1987-1993	A number of deposit banks encountered difficulties (including Denmark's ninth largest deposit bank, Varde Bank). In addition, the Faroe Islands experienced a banking crisis.	The government and Danmarks Nationalbank were involved in finding solutions for five distressed Danish deposit banks and for the banks on the Faroe Islands.	Currency crisis in the European Monetary System 1992-1993. Systemic banking crises in Norway, Sweden and Finland.
The International Financial Crisis 2008-2013	A number of deposit banks experienced difficulties and had to cease as independent firms (including several of the 15 largest deposit banks).	The government provided a safety net for the deposit banks via a comprehensive government guarantee for depositors *etc*. In addition, the government provided capital injections to a large number of credit institutions and gave credit institutions the opportunity to purchase an individual government guarantee on debt issues. Danmarks Nationalbank established additional credit facilities and expanded the collateral base for loans at the bank.	A liquidity crisis spread from the US to Europe in the second half of 2007, developing into a genuine global financial crisis in 2008. The financial crisis was followed by a government-debt crisis in several European countries.

Source: Based on Hansen and Svendsen (1968), Hoffmeyer and Olsen (1968), Mordhorst (1968), Mikkelsen (1993), Hoffmeyer (1993) and Abildgren *et al*. (2010).

Different criteria for defining and dating banking crises might lead to different results. Recently Chaudron and de Haan (2014) have analysed three databases of banking crises since the mid-1970s and evaluated their consistency in the identification and timing of the crises. They found large and statistically significant discrepancies between the databases.[2]

Even though a broader country coverage might be relevant, we focus on historical distributions of macro-financial risk factors for Denmark in this section. This partly reflects the need to respect the usual page limit for articles in this journal. However, it has also to be noted that the compilation of high-quality long-span time series requires a thorough country-specific knowledge of the economic-historical development in order to deal with the large number of judgements and estimations that implicitly or explicitly have to be made in order to overcome problems with missing observations, incomplete coverage and sampling biases, changes in compilation methods and statistical classifications *etc*. The main field of historical expertise of the author of this paper is the quantitative economic history of Denmark. However, references will be made to research findings for other countries. Furthermore, Section 5 discusses the potential value add-

2. There might seem to be a difference between Table 1 and the banking-crises chronology for Denmark in Reinhart and Rogoff (2009) regarding the dating of the banking crisis in the early 1900s. On page 243 and page 345 in Reinhart and Rogoff, *op. cit*., the year 1907 is stated as the beginning year of the crisis, which is the same year as applied in Table 1. However, on page 359 in Reinhart and Rogoff, *op. cit*., it is mentioned that there also was a banking crisis in February 1902. Such a crisis is neither mentioned in Danmarks Nationalbank's "Monetary History of Denmark" nor in the annual reports of Danmarks Nationalbank from 1901-1902 and 1902-1903. On the banking crisis in February 1902, Reinhart and Rogoff, *op. cit*., write as follows: "An important bank failure led to suspension of Freeholder's Bank and bank runs on other institutions. The National Bank helped alleviate panic; it took on the five remaining banks and suspended the banks' liabilities" (page 359 in Reinhart and Rogoff, 2009). Reinhart and Rogoff, *op. cit*., refer to Conant (1915) as the source for this information. However, in Conant, *op. cit*., Freeholder's Bank is only mentioned once in relation to the treatment of the crisis in 1907/1908: "The National Bank took an active part in allaying the tendency to panic which followed an important bank failure in the winter of 1908. The pressure in Germany reacted upon all the Scandinavian countries, and especially upon Copenhagen, by the withdrawal of foreign capital from Scandinavian enterprises. The result was the suspension on February 6, 1908, of the Freeholders' Bank (Grundejerbank), followed by a run on several institutions and a serious fall in the value of bank shares. The Retailers' Bank (Detailhandlerbank) in particular suffered a drop of twenty points in its shares and fears were entertained for its safety. Accordingly, on Sunday, February 9th, a meeting was called by the Minister of Finance, at which the National Bank and the four other leading banks were represented. It was finally decided that the Treasury and these five leading banks should jointly undertake a full guarantee not only for the liabilities of the suspended bank, but also for the Retailers' Bank" (page 300 in Conant, 1915). The exposition in Conant, *op. cit*., is thus fully in line with the treatment of the crisis in the Danish economic-historical literature, cf. for instance page 77 ff. in Rubow (1920), page 365 ff. in Cohn (1958), page 368 ff. in Hansen and Svendsen (1968), page 34 ff. in Hansen (1996) and page 101 ff. in Hansen and Mørch (1997).

ed of a broader country coverage and offers references to recent research projects in other countries on the construction of comprehensive databases with long-span historical economic, monetary and financial time series.

3.1. Risk factors driving the non-performance ratio of loans

The non-performance ratio of loans – i.e. non-performing loans as a share of credit exposures – in the banking sector will normally depend on developments in several macro-financial factors. Generally, experience shows that borrowers find it more difficult to service their loans in periods of economic downturn.

Real growth in GDP is often regarded to be a relevant driver of the banking sector's loan impairment charges on corporate credit exposures. When the economy is slowing down and firms' earnings are under pressure, there is a higher risk that the corporate borrowers fail to pay the instalments stipulated in their loan contracts.

In 2009, real GDP declined by 5.7 per cent. This was around 6 percentage points lower than forecasted by Danmarks Nationalbank in the 1st quarter of 2008. While around half of the forecast error could be attributed to lower export market growth and different developments in interest rates, exchange rates, oil prices and government demand than expected, the other half reflected "other factors". The "other factors" item covered many different factors, including those related to the financial crisis such as changes in private-sector consumption and investment behaviour in the wake of the global financial crisis that generally increased the uncertainty concerning the economic outlook and undermined confidence in the financial system. The "other factors" item may also reflect the effect of the deposit banks' need to tighten their credit terms and widen their interest margins in view of the cyclical reversal. This should be viewed in light of the lenient credit standards prior to the financial crisis (Abildgren *et al.*, 2011).

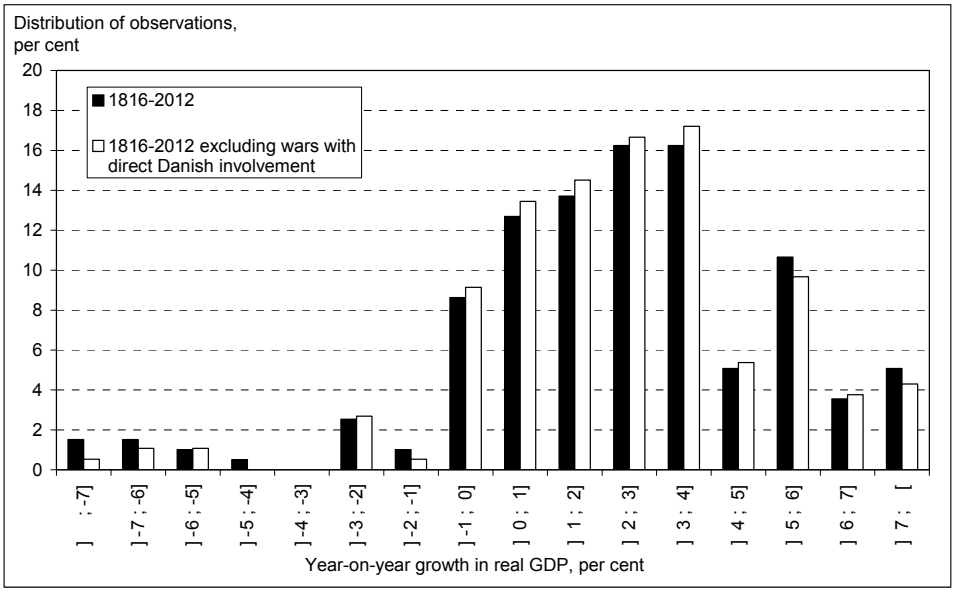
The 5.7 per cent drop in real GDP in 2009 was the largest annual decline in economic activity in Denmark since the end of World War II. However, since 1816 an annual drop in real GDP of 5 per cent or more has occurred in 8 of the 197 years during this period or around 4 per cent of the years, cf. Figure 1. Based on our historical experience since 1816, an annual drop in real GDP of 5 per cent or more can thus be expected to occur approximately once every 25 years.

If one excludes war periods with direct Danish involvement,[3] an annual drop in real GDP of 5 per cent or more has on average occurred once every 37 years. Most of these large declines in economic activity occurred during World War I

3. The definition of periods with wars with direct Danish involvement is as follows: The Great Nordic War (1709-1720), The Napoleonic Wars (1808-1813), The First Schleswig War (1848-1851 in annual data and 1848q1-1851q1 in quarterly data), The Second Schleswig War (1864 in annual data and 1864q1-1864q4 in quarterly data) and World War II (1940-1945 in annual data and 1940q2-1945q2 in quarterly data).

where Denmark was a neutral country. There was also a large drop in real GDP in 1856 where the international economy suffered from the so-called "peace crisis" after the end of the Crimean War.

Figure 1: Frequency distribution of year-on-year growth in real GDP

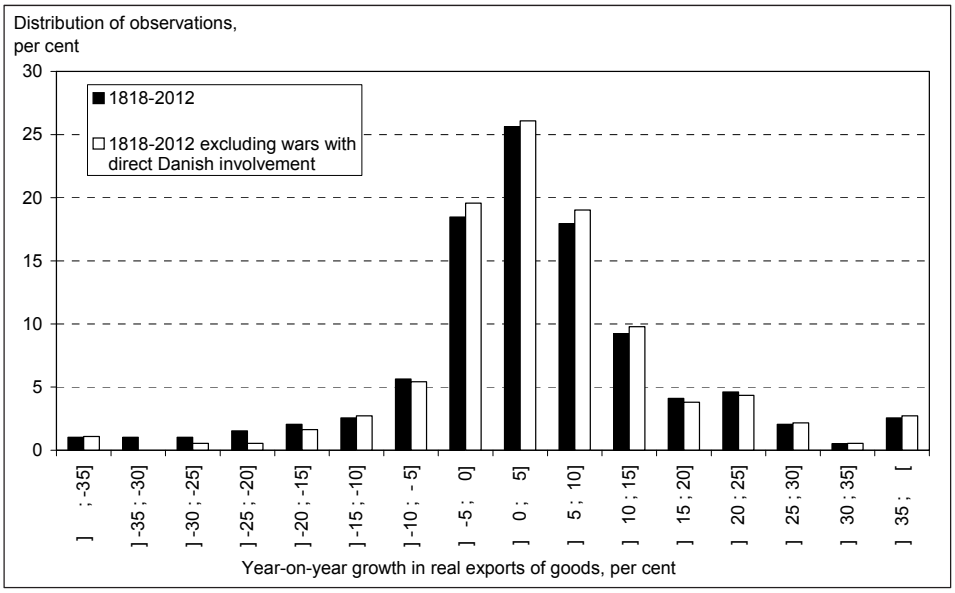


From the early 1920s to the early 1930s, Denmark experienced a period with severe banking crises where many banks ran into troubles, including all of the five main banks (Hansen, 1996). This period saw three years with an annual drop in real GDP in the range of 2-3 per cent. There was also a decline in real GDP of this magnitude in 1877 in the middle of the so-called Savings Bank Crisis.

Episodes of large declines in real GDP have historically naturally also occurred in other countries. Barro (2006) lists e.g. 65 episodes of a 15 percent or greater annual drop in real per capita GDP for 35 countries in the period 1900-2000.

The ratio of non-performing loans to export firms in the Danish banking sector depends crucially on international cyclical developments. In 2009, the real Danish exports of goods declined by almost 18 per cent. Since 1818, an annual drop in real exports of goods of 15 per cent or more has on average occurred approximately once every 15 years – or once every 26 years if one excludes war periods with direct Danish involvement, cf. Figure 2. Some of these large drops occurred during World War I. There was also e.g. a large decline in real exports in 1857 during the international monetary crisis.

Figure 2: Frequency distribution of year-on-year growth in real exports of goods



Note: Deflated by the CPI.

The years 1931 and 1932 during the Great Depression saw declines in real exports of goods in the range of 12-14 per cent per annum, and the 1920s saw three years with an annual decline in real exports of more than 10 per cent.

Movements in the unemployment rate are usually considered to be a key driver for impairment charges on loans to households since unemployment reduces the households' ability to pay. In 2009, the unemployment rate in Denmark increased by 1.7 percentage points. Based on the experiences since 1901, an annual increase in the rate of unemployment of 1.5 percentage points or more has occurred once every 18 years on average (disregarding wars with direct Danish involvement), cf. Figure 3. The largest increases in the unemployment rate occurred in the interwar period and following the oil price shocks of the 1970s.

Not only the size of an increase in the unemployment rate but also the level of the unemployment rate might be of importance for the impact on the financial sector of negative shocks to the economy. Households may have weaker balance sheets if the economy is in a state of a high level of unemployment rate prior to the shock.

At the outbreak of the most recent financial crisis in 2008, the unemployment level was very low (1.9 per cent) and in 2012 it was still relatively low (4.4 per cent), cf. Figure 4. The same was the case during the interwar banking crisis in the 1920s and early 1930s. In contrast, the level of unemployment was very high (9-12 per cent) during the banking crisis in the early 1990s.

Figure 3: Frequency distribution of year-on-year change in unemployment rate

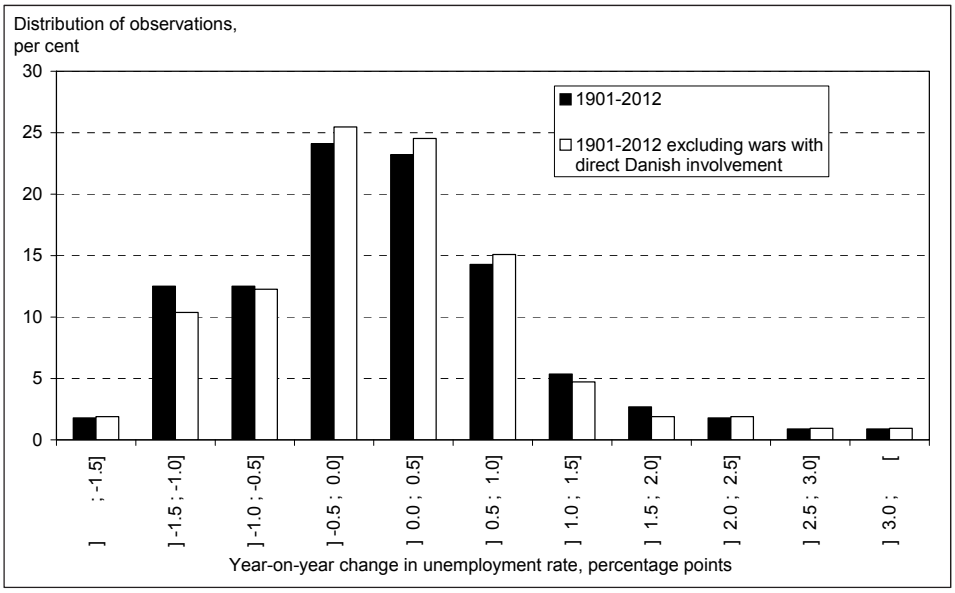
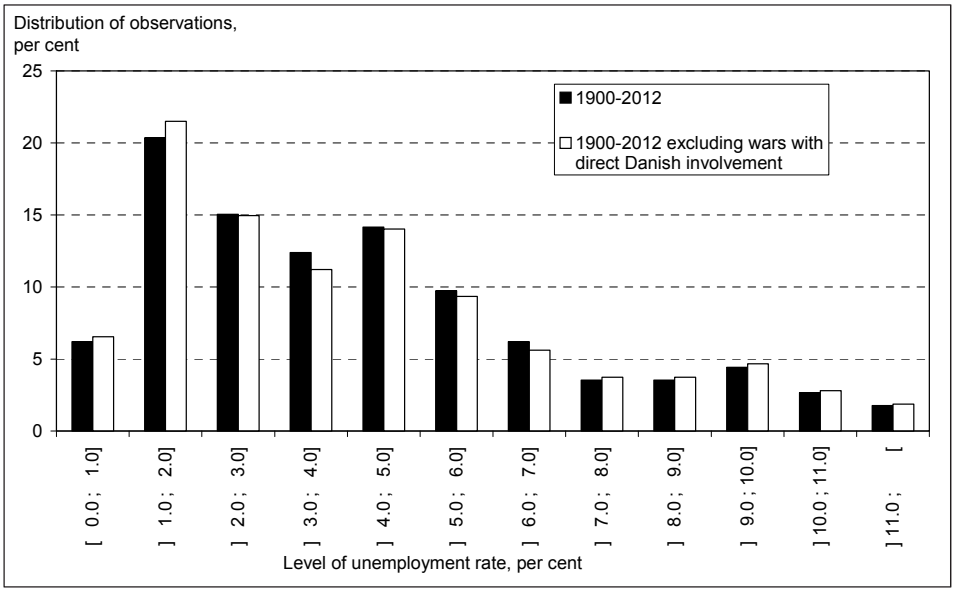


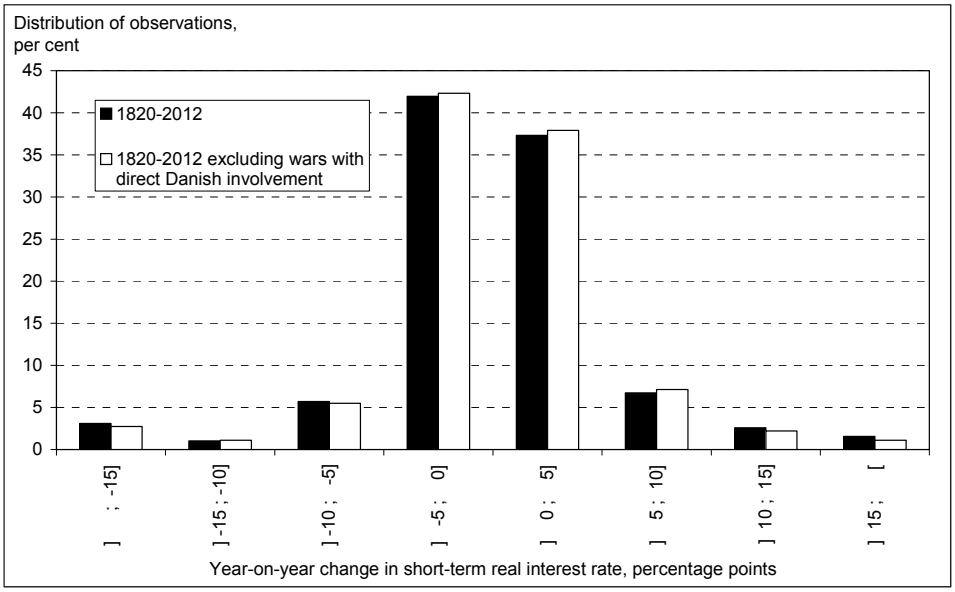
Figure 4: Frequency distribution of the level of unemployment rate



Rising short-term real interest rates are usually expected to increase the loan impairment charge ratio of banking institutions, since a higher level of real interest rates increases the real interest burden of households and firms.

The year 2009 saw a modest drop in the short-term real interest rate in Denmark. However, Danish economic history has seen many cases of substantial increases in the short-term real interest rate, cf. Figure 5. Disregarding wars with direct Danish involvement, an annual increase in the short-term real interest rate by 5 percentage points or more has occurred once every 10 years on average since 1820. Some of the large increases in the short-term real interest rate occurred in periods with deflation or large drops in the inflation rate. There were e.g. large increases in the short-term real interest rate during the deflation periods in the 1820s (dominated by crises within the Danish agricultural sector) and in the 1920s (characterised by a severe banking crisis) as well as during The Monetary Crisis 1857-1858.

Figure 5: Frequency distribution of year-on-year change in short-term real interest rate



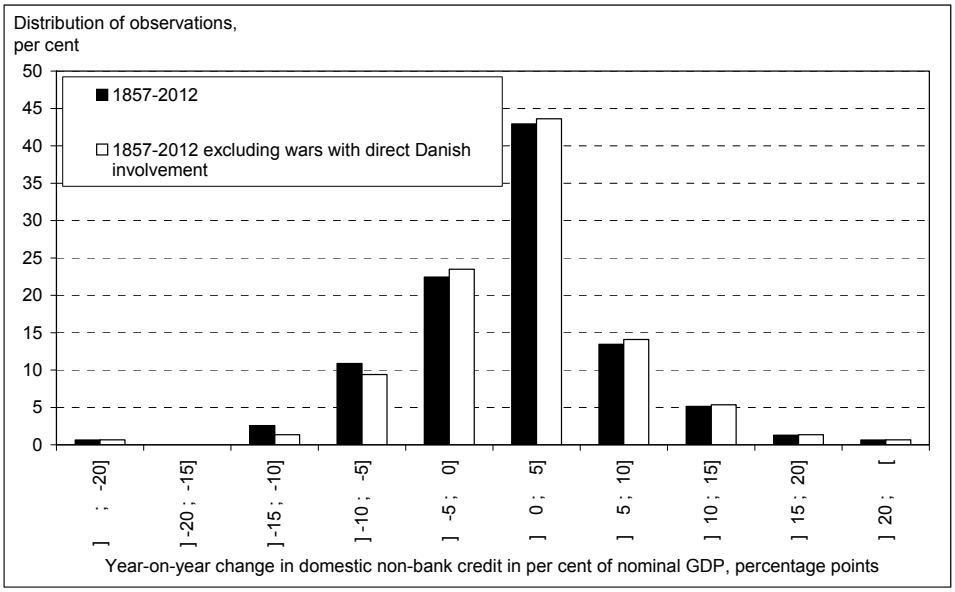
Note: Measured as the difference between the contemporaneous lending rate of Danmarks Nationalbank and the contemporaneous rate of consumer price inflation.

Usually, credit risk is assumed to increase in step with the rise of the debt-to-income ratio of the borrowers. Furthermore, it might be argued that credit quality tends to deteriorate during periods of strong lending growth (Cardarelli *et al.*, 2011; Festic *et al.*, 2011).

Prior to the recent financial crisis there was a rapid growth in domestic credit relative to GDP in Denmark. In each of the years during the period 2005-2008, domestic non-bank credit in per cent of GDP grew by 14-16 percentage points. An annual increase in the debt-to-GDP ratio by 10 percentage points or more has oc-

curred once every 14 years on average since 1857, cf. Figure 6. There were also large annual increases in the debt-to-income ratio in 1906 just prior to the Construction and Banking Crisis, in the early 1920s prior to the first reconstruction of Landmandsbanken – at that time the largest bank in Scandinavia – and in 1986 just prior to the banking crisis in the late 1980s and early 1990s.

Figure 6: Frequency distribution of year-on-year change in domestic non-bank credit in per cent of nominal GDP



Note: Covers domestic non-bank credit extended by resident commercial banks, savings banks and mortgage banks.

3.2. Risk factors driving loss on loans given default

Loss given default – i.e. the share of the non-performing loans that should be regarded as lost in the event of default of the debtor – depends among other things on the extent and quality of the collateral pledged by the debtor in connection with the loan. The value of the collateral will normally be related to macro-financial factors, for instance property prices if the collateral for a loan consists of real estate.

In 2009, the price of one-family houses declined by 12 per cent. This was the largest drop in nominal house prices since 1939.

Disregarding World War II an annual drop in nominal house prices of 5 per cent or more has occurred once every 17 years on average since 1939, cf. Figure 7. The second half of the 1980s and early 1990s saw two cases of decline in nominal house prices by more than 5 per cent per annum.

Figure 7: Frequency distribution of year-on-year growth in nominal house prices

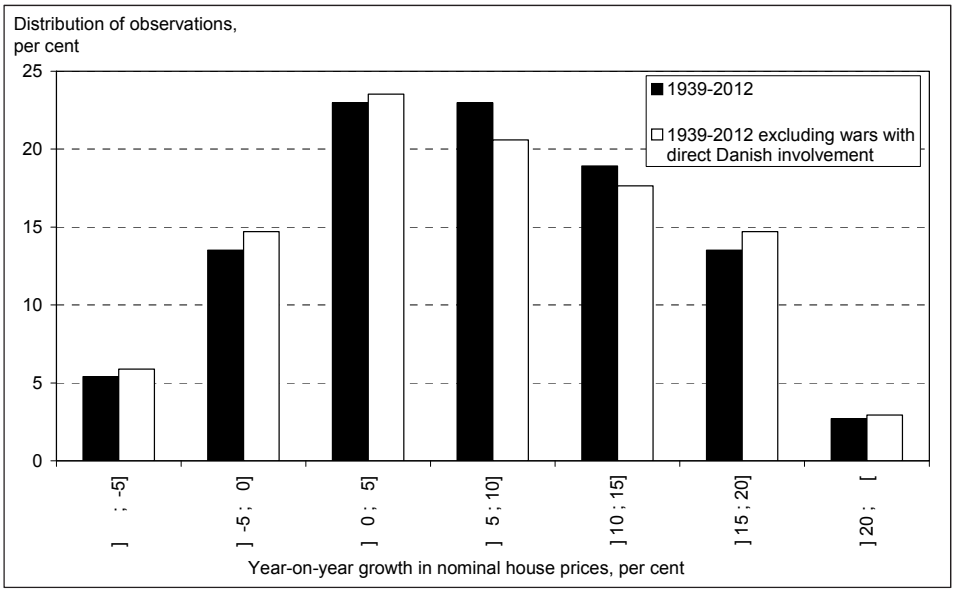
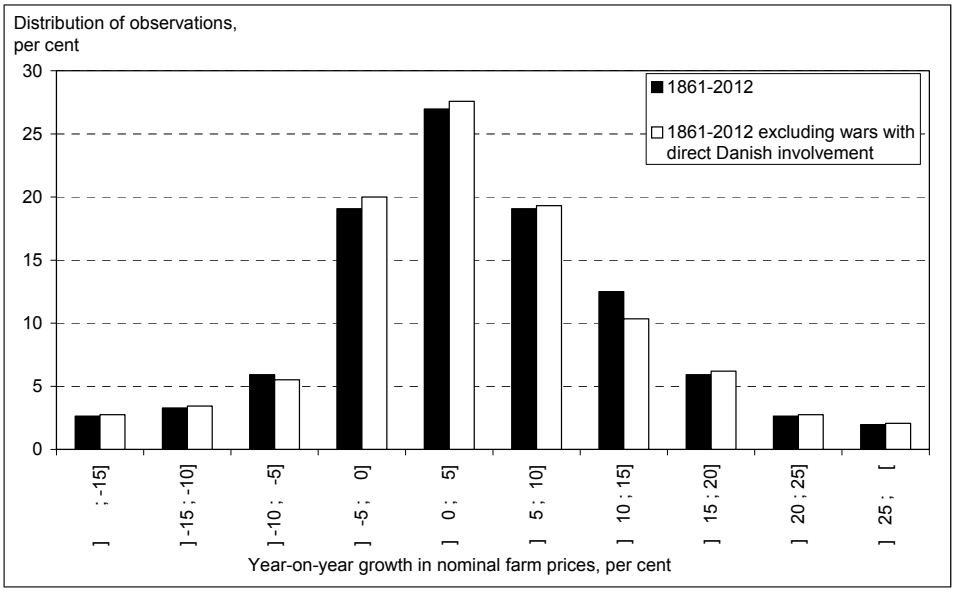


Figure 8: Frequency distribution of year-on-year growth in nominal farm prices



However, it must be kept in mind that the time series on nominal house prices is relative short and that a large part of the time span covered by the series includes the 1960s and 1970s with a high and rising consumer price inflation. There has

therefore been a positive growth rate in nominal house prices during most of the sample period.

The price index for sale of farms in Denmark declined by 16 per cent in 2009. This was the largest annual nominal drop in farm prices since 1861. An annual drop in nominal farm prices of 5 per cent or more has occurred once every 8 years on average since 1861 – or once every 9 years excluding periods with wars with direct Danish involvement, cf. Figure 8. Most of these large annual declines in farm prices have occurred during and following the most recent financial crises, in the early 1980s, during the banking crisis in the 1920s and early 1930s and during The Savings Bank Crisis 1876-1878.

Large drops in property prices around financial crises have also been found for other countries, for instance in Norway (Eitrheim and Erlandsen, 2005; Riiser, 2005) and the United States (Glaeser, 2013).

3.3. Risk factors driving market risks

Financial institutions usually hold large portfolios of financial assets (including derivatives) on their balance sheets stated at market values. Market risk is the risk of losses as a consequence of asset-price fluctuations. The main macro-financial risk factors behind market risk are share prices, long-term interest rates and exchange rates.

Value adjustments of shares traditionally show a high degree of volatility. From end of 2008 to end of 2009, the total share price index in Denmark declined by almost 47 per cent. This was the largest annual nominal drop in end-of-year share prices since 1874. An annual drop in nominal end-of-year share prices of 20 per cent or more has occurred once every 13 years on average since 1874 if one disregards the development during World War II, cf. Figure 9. Several of these large annual drops in share prices occurred during the banking crisis in the early 1920s. There was also a large drop in share prices after the first oil price shock in the 1970s, during the currency crisis in Europe in 1992, and in 2002 following corporate accounting scandals in the United States.

Due to the high volatility of share prices, it might be of interest to study the distribution of price movements at a higher frequency than annual. In the fourth quarter of 2008 – following the collapse of the American investment bank Lehman Brothers – the total share price index in Denmark declined by more than 29 per cent. This was the largest quarterly nominal drop in end-of-quarter share prices since the second quarter of 1915, cf. Figure 10. A quarterly drop in share prices of more than 20 per cent also occurred in third quarter of 2002 following corporate accounting scandals in the United States and in the third quarter of 1992 following the outbreak of a currency crisis in Europe. There were e.g. also large declines in stock prices in the third quarter of 2001 (after the terrorist attacks on the USA on 11 September) and in the third quarter of 1998 (after Russia had

suspended payments on foreign debt and a large US hedge fund, Long Term Capital Management, LTCM, experienced problems).

Figure 9: Frequency distribution of year-on-year nominal growth in the total share price index in Denmark (based on end-of-year data)

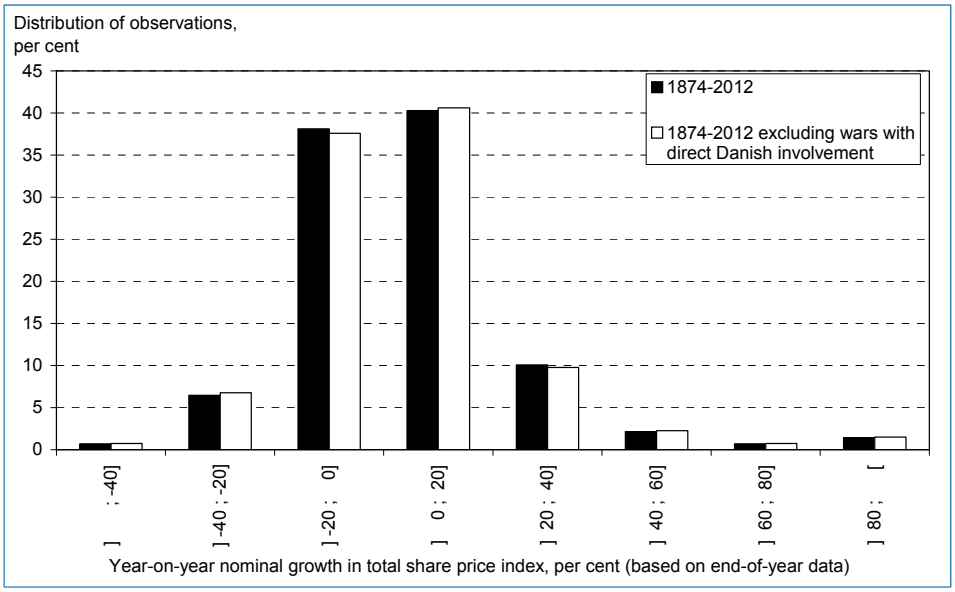
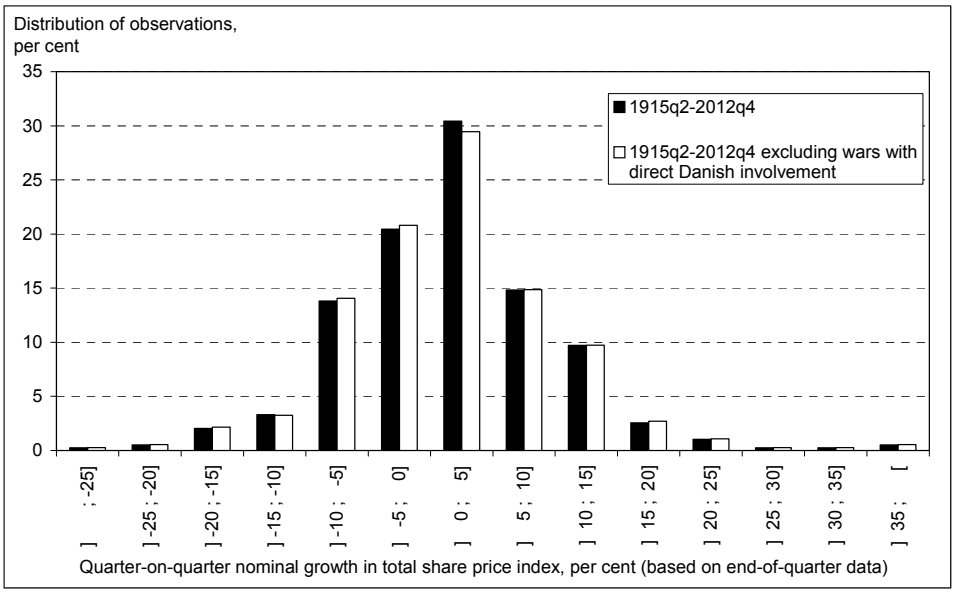


Figure 10: Frequency distribution of quarter-on-quarter nominal growth in the total share price index (based on end-of-quarter data)



Financial institutions in Denmark might have exposures in foreign shares and therefore also be subject to price risks on foreign stock markets. In a recent study Mehl (2013) identified 43 global stock market volatility shocks over the period 1885-2011 based on monthly data for 17 countries. On average, global equity market valuations corrected by about 20 per cent in the month when such shocks occurred. The three largest stock market shocks in this study were the crash in 1929, the crash following the collapse of Lehman Brothers in 2008 and the "Black Monday" crash in 1987. In another study on the Dow Jones Industrial Average (DJIA) index based on daily data from the period 1928-2013, Charles and Darné (2014) found large shocks in the volatility of the DJIA in relation to major financial crashes, US elections, wars, macroeconomic news, terrorist attacks, bankruptcy, and regulation.

Market risk related to bond portfolios is primarily related to the market value of bonds with long duration, that all else equal declines when long-term interest rates increases. The most important long-term domestic bonds in the portfolio of financial institutions in Denmark are Danish government bonds and Danish mortgage bonds.

The annual average nominal yield to maturity of long-term Danish government bonds as well as long-term Danish mortgage bonds declined in 2009. However, Danish economic history has seen several cases of increases in the long-term nominal interest rates, cf. the frequency distributions of changes in long-term nominal interest rates based on quarterly average data in Figure 11 and 12.

Figure 11: Frequency distribution of quarter-on-quarter change in long-term nominal yield on government bonds (based on quarterly average data)

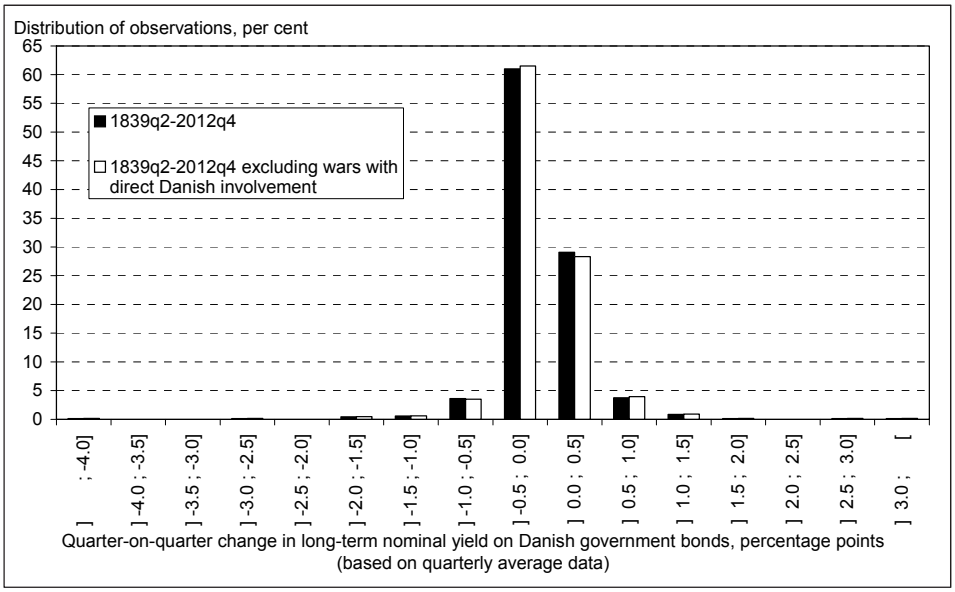
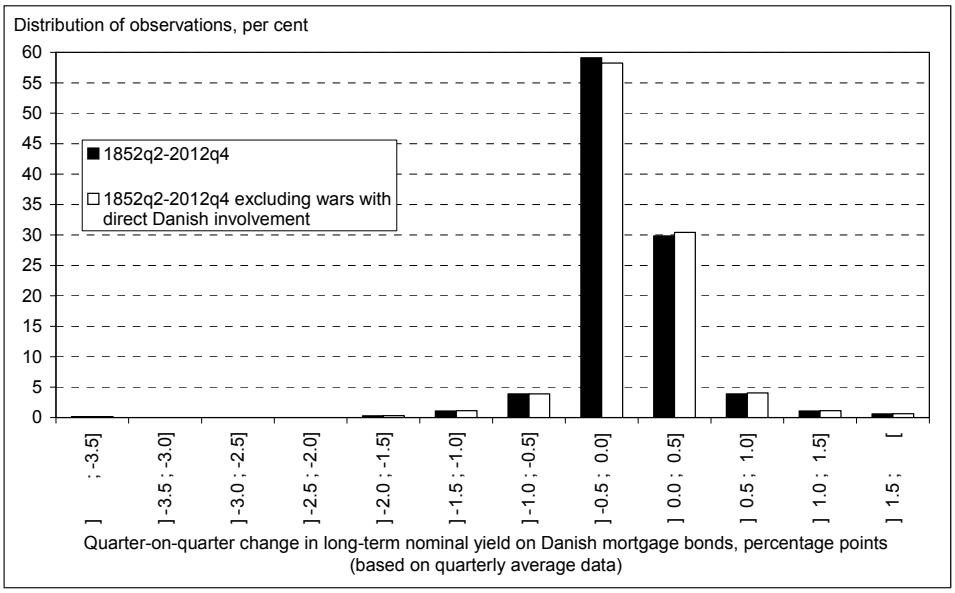


Figure 12: Frequency distribution of quarter-on-quarter change in long-term nominal yield on mortgage bonds (based on quarterly average data)

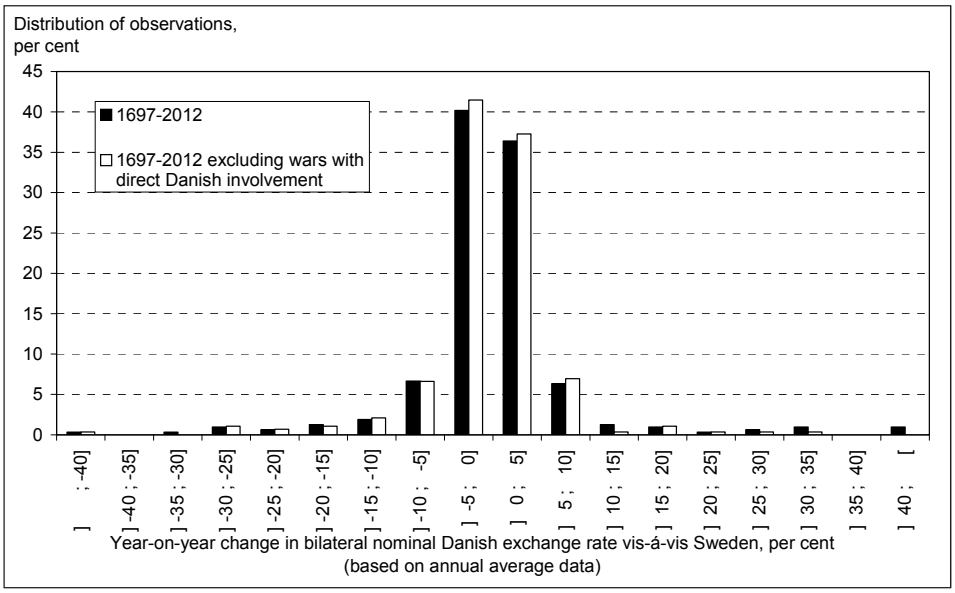


In the early 1980s, there were two quarters where the nominal long-term government bond yield increased by 2-3 percentage points from one quarter to another. It might also be noted that the nominal long-term government bond yield increased by around 5 percentage points in total from the second quarter of 1979 to the second quarter of 1980 when the government ran large budget deficits. During the same period, the yield on long-term mortgage bonds increased only by around 2.5 percentage points. As a result, the yield on long-term Danish government bonds exceeded the yield on long-term Danish mortgage bonds in the beginning of the 1980s. Previously, this had only occurred during World War I and II. The nominal long-term mortgage bond yield increased by around 5 percentage points in total from the second quarter of 1973 to the second quarter of 1974 following the first oil price shock of the 1970s.

A historical perspective on interest-rate risk related to long-term government bonds in eight foreign countries is offered by Gerlach *et al*. (2006) whereas Giesecke *et al*. (2011, 2014) cover US corporate bonds. More than 50 per cent of all outstanding corporate bonds in the US defaulted during the years 1871-1879 when many railroads ran into difficulties after a period of rapid expansion.

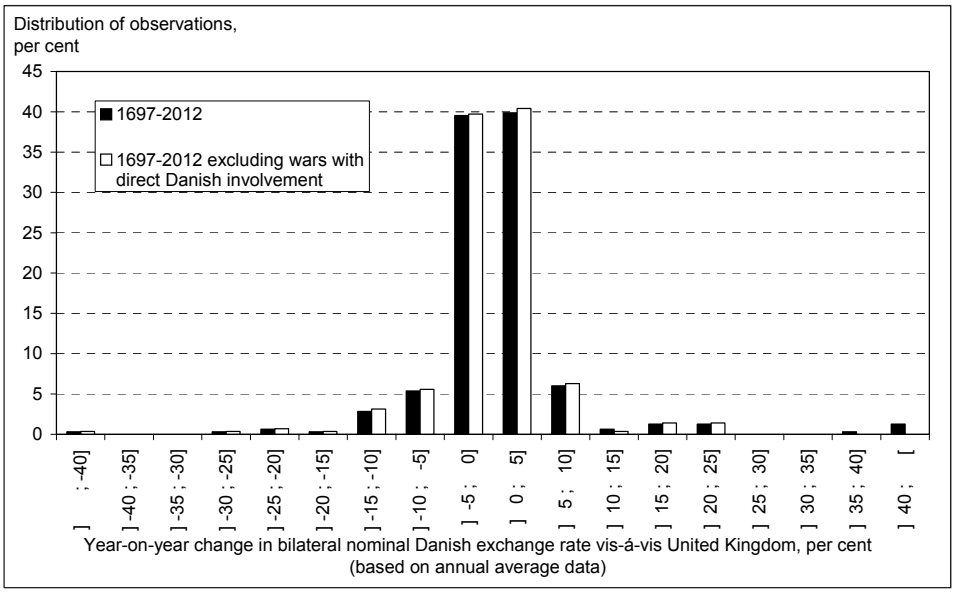
Finally, experience shows that exchange rates can fluctuate quite considerably and thereby lead to substantial losses on foreign-exchange rate exposures. Figures 13-14 show the annual average changes in the Danish bilateral nominal exchange rate vis-à-vis Sweden and United Kingdom in a long-term historical perspective. An increase denotes a depreciation of the Danish currency.

Figure 13: Frequency distribution of year-on-year change in bilateral nominal Danish exchange rate vis-à-vis Sweden (based on annual average data)



Note: An increase denotes a depreciation of the Danish currency.

Figure 14: Frequency distribution of year-on-year change in bilateral nominal Danish exchange rate vis-à-vis United Kingdom (based on annual average data)



Note: An increase denotes a depreciation of the Danish currency.

A depreciation of the Danish exchange rate makes it more expensive to service foreign-currency denominated debt if the base-currency is Danish. Disregarding wars with direct Danish involvement, an annual average depreciation of the Danish bilateral nominal exchange rate by 5 per cent or more has occurred once every 10-11 years vis-à-vis Sweden and the United Kingdom.

An appreciation of the Danish exchange rate lowers the value of foreign-currency denominated assets if the base-currency is Danish. Disregarding wars with direct Danish involvement, an annual average appreciation of the Danish bilateral nominal exchange rate by 5 per cent or more has occurred once every 8-10 years vis-à-vis Sweden and the United Kingdom.

Abildgren (2014) offers a closer look at the frequency distribution of nominal price changes in the foreign exchange markets for a sample of 10 European exchange-rate pairs on the basis of a quarterly data set spanning 273 years.

4. The scope for using historical distributions in macro stress tests

In Section 3, we looked at the marginal (also referred to as "unconditional") historical distribution of each macro-financial risk factor in isolation. There are several ways that such distributions based on long-span historical time series can serve as inspiration in relation to macro stress tests of the financial system.

First, one can make use of shocks drawn from historical distributions of macro-financial risk factors as the basis for low-probability scenarios. By using distributions derived from long-span rather than short-span time series one avoids the risk of facing the "small-sample problem" outlined in Section 2.

Second, they might be used in simple static sensitivity analyses. In a sensitivity analysis one assesses how a large shock to a single macro-financial risk factor in isolation – for instance a 20 per cent drop in stock prices – affects the resilience of the financial system, all other things being equal, and the historical distribution allows in principle for an evaluation of the likelihood of such a shock under the assumption of fixed distributions. Simple sensitivity analysis can often be based directly on risk exposures derived from the balance-sheet statements and risk reports of financial institutions without the need for a macroeconomic model.

Third, they might be used to identify relevant historical scenarios of interest if one prefers to use a specific historical episode as a scenario instead of drawing shocks from the tails of historical distributions of risk factors. If the current focus among the authorities, for instance, is resilience of the financial system to a large drop in farm prices, one can use the historical distribution of changes in farm prices to identify those historical periods where large drops have occurred. Those historical periods can then be used as stress scenarios, taking into account the movements of all other macro-financial risk factors in those periods as well.

Fourth, they might be used for so-called "reverse stress testing" (Breuer *et al*., 2012). If the current focus among the authorities is resilience of the financial system to rising long-term interest rates, we can calculate the increase in long-term interest rates that the financial system can handle without a need for further capitalisation. We can then use the historical distributions to get an idea of the likelihood of an increase in long-term interest rates of this magnitude.

Finally, they can be used as a source of inspiration for designing "worst case" scenarios. A "worst case" scenario could for instance be the simultaneous occurrence of the largest drop in farm prices and the largest increase in long-term interest rates that we have experienced in the economic history of Denmark covered by our historical statistics.

Naturally, we can't evaluate the probability of such "worst case" scenarios based solely on marginal historical distributions of each macro-financial risk factor in isolation. Furthermore, it might be argued that some "worst case" scenarios are not plausible or internally consistent based on conventional economic theory (Schuermann, 2014). However, "worst case" scenarios based on inspiration from economic history should be seen as more in line with a traditional ad-hoc "risk management" approach. With "worst case" scenarios, the sensitivity of the financial system to large shocks to selected macro-financial risk factors is uncovered without at the same time determining the exact likelihood of the scenarios.

To address the risk that "worst case" scenarios are considered too implausible, one might consider the use of conditional scenarios. If e.g. the focus is on the financial system's resilience to a large drop in stock prices, one could find those years where stock prices declined by 10 per cent or more from one year to another. One could then randomly pick one of those years and use the actual historical values of all macro-financial risk factors for this year and the following years as the stress scenario. Alternatively, one could use the average values of the risk factors in those years (and the following years) as the stress scenario, cf. also Buncic and Melecky (2013) for a somewhat similar approach based on cross-country data.

Another way to partly take into account the correlations between the macro-financial risk factors is to consider the use of mixed scenarios based on linear combinations of historical outcomes in different periods. This could for instance be a linear combination of the outcomes from the years characterised by large drops in house prices, real GDP and real exports with the outcome from the years characterised by a large increase in long-term interest rates (Breuer and Csiszár, 2013).

5. Limitations to the use of historical distributions in macro stress tests

Even though it can be useful to have an eye for the long-term historical perspective as a source of inspiration when designing low-probability scenarios in relation to macro stress tests, all approaches naturally have pros and cons. We have therefore also to highlight a number of challenges and limitations that are related to the use of long-span historical time series as a source of low-probability scenarios.

5.1. Marginal versus simultaneous distributions of risk factors

In this article, we have so far only looked at the marginal historical distribution of each macro-financial risk factor in isolation, and naturally simultaneous historical distributions would be of even greater interest.

However, for simultaneous historical distributions not even annual or quarterly data sets spanning several centuries are sufficient – at least not based on long historical time series for a single country. In the non-parametric econometric literature, this problem is usually referred to as "the curse of dimensionality" (Li and Racine, 2007; Ahamada and Flachaire, 2010). To illustrate the point, just think of five different macro-financial risk factors where the outcome of each factor is classified into five different categories. This gives 3,125 different possible simultaneous outcomes. With an annual or quarterly data set for only one country spanning at best a couple of centuries, estimation of simultaneous distributions would require strong *a priori* assumptions regarding the form of the multivariate distributions followed by the macro-financial risk factors.

The importance of simultaneous distributions might be illustrated by a closer look at the economic developments during the periods with banking crises in Danish economic history since 1857. Table 2 shows the occurrence of events in the 10 per cent tails during these periods. The Table clearly underlines that banking crises can be very different and that simultaneous distributions matter, cf. also Sayek and Taskin (2014). The most recent International Financial Crisis 2008-2012 was characterised by large drops in real GDP, real exports and asset prices. However, there were no large shocks to interest rates and the level of unemployment has been very low in Denmark. In contrast the Seven-Year Slump 1987-1993 saw high levels of unemployment rates but no large drops in real GDP or real exports. The Interwar Banking Crisis was characterised by a broad range of negative shocks whereas the Liquidity Crisis of 1885, the Construction and Banking Crisis 1907-1909 and the Kronebank Crisis 1984-1985 occurred despite the absence of large drops in e.g. the total economy real GDP.

Table 2: Occurrence of events in the 10 per cent tails during banking crises in Danish economic history since 1857

	Banking crisis							
	The Monetary Crisis	The Savings Bank Crisis	The Liquidity Crisis	The Construction and Banking Crisis	The Interwar Banking Crisis	The Kronebank Crisis	The Seven-Year Slump	The International Financial Crisis
Macro-financial risk factor	1857-1858	1876-1878	1885	1907-1909	1920-1933	1984-1985	1987-1993	2008-2012
Drop in real GDP	YES	YES	NO	NO	YES	NO	NO	YES
Drop in real exports	YES	YES	NO	NO	YES	NO	NO	YES
Increase in unemployment rate	n.a.	n.a.	n.a.	NO	YES	NO	NO	YES
High level of unemployment	n.a.	n.a.	n.a.	NO	NO	NO	YES	NO
Increase in real short-term interest rate	YES	NO	NO	NO	YES	NO	NO	NO
Drop in nominal house prices	n.a.	n.a.	n.a.	n.a.	n.a.	NO	YES	YES
Drop in nominal farm prices	n.a.	NO	NO	NO	YES	NO	NO	YES
Drop in nominal share prices	n.a.	NO	NO	NO	YES	NO	YES	YES
Increase in nominal government bond yields	NO	NO	NO	NO	YES	NO	YES	NO
Increase in nominal mortgage bond yields	NO	NO	NO	NO	YES	NO	YES	NO
Depreciation of the Danish currency vis-a-vis Sweden	NO	NO	NO	NO	YES	NO	NO	YES
Appreciation of the Danish currency vis-a-vis Sweden	NO	NO	NO	NO	YES	NO	YES	YES
Depreciation of the Danish currency vis-a-vis U.K.	NO	NO	NO	NO	YES	NO	YES	YES
Appreciation of the Danish currency vis-a-vis U.K.	NO	NO	NO	NO	YES	NO	YES	YES
Depreciation of the Danish currency vis-a-vis U.S.	NO	NO	NO	NO	YES	YES	NO	NO
Appreciation of the Danish currency vis-a-vis U.S.	NO	NO	NO	NO	YES	NO	YES	NO
Depreciation of the Danish currency vis-a-vis Norway	NO	NO	NO	NO	YES	NO	NO	YES
Appreciation of the Danish currency vis-a-vis Norway	NO	NO	NO	NO	YES	NO	YES	YES
Depreciation of the Danish currency vis-a-vis Switzerland	NO	NO	NO	NO	YES	NO	NO	YES
Appreciation of the Danish currency vis-a-vis Switzerland	NO	NO	NO	NO	YES	YES	YES	NO

Notes: n.a. denotes that data are not available.
The 10 per cent tails are based on the distributions of all available data on an annual frequency (including war periods).

5.2. Sample selection

An expansion of the country coverage might be a way to address the issue of insufficient observations in relation to the estimation of simultaneous historical distributions of macro-financial risk factors.

In recent years, Norges Bank[4] and Sveriges Riksbank[5] have published comprehensive collections of long-span historical economic, monetary and financial time series. Several other central banks have also recently focused on the construction of long-span historical time series, including Bank of England,[6] Swiss National Bank,[7] Banca D'Italia[8] and a range of central banks from South-Eastern Europe.[9] The BIS[10] and IMF[11] have also offered collections of historical statistics. In time, such efforts from the central-banking community might generate databases with sufficient historical statistics to allow us to get a picture of the joint historical distributions of some of those macro-financial risk factors that drive financial instability.

Naturally, there is a range of issues to consider if distributions of macro-financial risk factors are estimated from a larger sample of countries. The degree of macroeconomic volatility of a country might depend on e.g. institutional factors, the per capita income level and the degree of diversification of the business sector, *etc*. (Jones and Olken, 2008). The same arguments could also be made in relation to the use of long time series for a single country.

A broader country coverage would in principle allow for the control for more factors, including institutional factors such as type of exchange-rate regime, degree of cross-border capital control, the industrial structure, the income level *etc*. With large data samples one could e.g. exclude data from selected periods in order to avoid the use of "wrong historical analogies". However, it might be argued that one should allow for the possibility of regime switches when drawing shocks from the tails of historical distributions of relevant risk factors for stress scenarios, since regime switches with the current modelling techniques are hard to capture in the model part of a macro stress testing framework.

5.3. Uncertainty related to long-span economic-historical time series

Historical statistical data within the social sciences are always subject to questions regarding their accuracy and reliability. Frequently a number of judgements and

4. Cf. Eitrheim *et al*. (eds) (2004, 2007).
5. Cf. Edvinsson *et al*. (eds) (2010, 2014)
6. Cf. Dimsdale *et al*. (2010).
7. Cf. Balmer (2007), Baumgartner (2007), Halbeisen and Maurer (2007), Selz (2007) and Rosenfellner and Wermelinger (2009).
8. Cf. Panetta and Violi (1999), Baffigi (2011) and De Bonis *et al*. (2012).
9. Cf. Bank of Greece *et al*. (2014).
10. Cf. Dembiermont *et al*. (2013) and Scatigna *et al*. (2014).
11. Cf. Abbas *et al*. (2011).

estimations have implicitly or explicitly been made in an attempt to overcome problems with missing observations, incomplete coverage and sampling biases, changes in compilation methods and statistical classifications *etc*., and the methods commonly used to address such issues all have pros and cons.[12] Furthermore, sometimes historical statistical information have originally been collected for particular legal or political purposes, which have to be taken into account when the reliability of such data sets are assessed.

Naturally such uncertainties call for caution when using distributions of macro-financial risk factors based on long-span historical time series. However, it should also be noted that even contemporary economic statistics are subject to frequent and large revisions, for instance in relation to so-called benchmark revisions of the national accounts statistics when new international standards for the methodological principles are implemented.

5.4. Government support measures

Historically, extensive support measures from the authorities such as government guarantees or capital injections in the financial sector have in several cases been implemented during periods with financial crisis. Without such initiatives, the historical economic outcome of the macro-financial risk factors during periods of financial crises would undoubtedly have been different.

If one wishes to construct stress scenarios for an assessment of the resilience of the financial system to negative economic shocks without such support measures, one cannot make use of specific historical crises episodes as stress scenarios. Structural economic models are needed if one wishes to control for the effect of government support measures, although such models might be hard to develop.

5.5. Communication issues

It might be argued that purely "statistical approaches" without the use of an economic model such as the historical sensitivity tests suggested in Section 4 are less suitable in the context of macro-prudential surveillance due to the importance of storytelling in the communication of macroprudential policy initiatives (Foglia, 2009). The key stories of the outcome of stress scenarios are usually easier to tell within the framework of structural economic models. Furthermore, a structural approach with explicit modelling of behaviour is often needed if one wishes to implement macro-prudential regulations aimed at changing the future behaviour in the banking sector or among firms and households.

12. De la Escosura (2014) discusses the pros and cons of various methods commonly used to adjust for break between old and new data series.

6. Final remarks

The macro stress tests used by the authorities in many countries prior to the most recent financial crisis did not pay sufficient attention to low-probability but high-consequence scenarios. In this article we have argued to make use of distributions of macro-financial risk factors based on long-span historical time series as inspiration in relation to low-probability scenarios in macro stress tests.

Even though it can be useful to have an eye for the long-term historical perspective when designing low-probability scenarios in relation to macro stress tests all approaches naturally have pros and cons, and we have outlined and discussed a number of challenges and limitations that are related to the use of long-span historical time series as a source of low-probability scenarios.

Recently, Eichengreen (2012) has pointed at economic history as a tool to make sense of a financial crisis and shape economic-policy responses. Perhaps the most important contribution from analyses of distributions of macro-financial risk factors based on long-span historical time series is that they serve as a memory of the past. They remind us that extreme events might occur more often than we would think, if we only relied on an historical experiences from relative short data samples.

References

Abbas, S.M.A., N. Belhocine, A. El-Ganainy and M. Horton. 2011. Historical Patterns and Dynamics of Public Debt – Evidence From a New Database, *IMF Economic Review*, Vol. 59(4), pp. 717-742.

Abildgren, K. 2013. Stress scenarios from the tails of historical distributions of macro-financial risk factors in Denmark, *Danmarks Nationalbank Working Papers*, No. 86.

Abildgren, K. 2014. Tail events in the FX markets since 1740, *Journal of Risk Finance*, Vol. 15(3), pp. 294-311.

Abildgren, K. and J. Damgaard. 2012. Models for Banks' Loan Impairment Charges in Stress Tests of the Financial System, *Danmarks Nationalbank Monetary Review*, Vol. 51(1,2), pp. 57-101.

Abildgren, K. with an introductory chapter by B.N. Andersen and J. Thomsen. 2010. Monetary History of Denmark 1990-2005, Copenhagen: Danmarks Nationalbank.

Abildgren, K., B.V. Buchholst, A. Qureshi and J. Staghøj. 2011. Real Economic Consequences of Financial Crises, *Danmarks Nationalbank Monetary Review*, Vol. 50(3,2), pp. 1-49.

Ahamada, I. and E. Flachaire. 2010. *Non-Parametric Econometrics*, Oxford: Oxford University Press.

Ahmad, F. and T. Bashir. 2013. Explanatory Power of Macroeconomic Variables as Determinants of Non-Performing Loans: Evidence from Pakistan, *World Applied Sciences Journal*, Vol. 22(2), pp. 243-255.

Alfaro, R. and M. Drehmann. 2009. Macro stress tests and crises: what can we learn?, *BIS Quarterly Review*, December, pp. 29-41.

Ali, A. and K. Daly. 2010. Macroeconomic determinants of credit risk: Recent evidence from a cross country study, *International Review of Financial Analysis*, Vol. 19, pp. 165-171.

Asai, M., M.K.P. So and J. Wong. 2013. Stress testing correlation matrices for risk management, *North American Journal of Economics and Finance*, Vol. 26, pp. 310-322.

Baffigi, A. 2011. Italian National Accounts, 1861-2011, *Banca d'Italia Economic History Working Papers*, No. 18.

Balmer, S. 2007. The monetary base and the M1, M2 and M3 monetary aggregates, *SNB Historical Time Series*, Vol. 1.

Bank of Greece, Bulgarian National Bank, National Bank of Romania and Oesterreichische Nationalbank. 2014). *South-Eastern European Monetary and Economic Statistics from the Nineteenth Century to World War II*, Vienna: Oesterreichische Nationalbank.

Barro, R.J. 2006. Rare disasters and asset markets in the twentieth century, *Quarter Journal of Economics*, Vol. 121(3), pp. 823-866.

Baumgartner, R. 2007. Interest rates and yields, *SNB Historical Time Series*, Vol. 4.

Billio, M., M. Getmansky, D. Gray, A.W. Lo, R.C. Merton and L. Pelizzon. 2013. On a New Approach for Analyzing and Managing Macrofinancial Risks, *Financial Analysts Journal*, Vol. 69(2), pp. 22-33.

De Bonis, R., F. Farabullini, M. Rocchelli and A. Salvio. 2012. A Quantitative Look at the Italian Banking System: Evidence from a new Dataset since 1861, *Banca d'Italia Economic History Working Papers*, No. 26.

Bordo, M., B. Eichengreen, D. Klingebiel and M.S. Martinez-Peria. 2001. Is the crisis problem growing more severe?, *Economic Policy*, Vol. 16, pp. 53-82.

Borio, C., M. Drehmann and K. Tsatsaronis. 2014. Stress-testing macro stress testing: does it live up to expectations?, *Journal of Financial Stability*, Vol. 12, pp. 3-15.

Breuer, T. and I. Csiszár. 2013. Systematic stress tests with entropic plausibility constraints, *Journal of Banking & Finance*, Vol. 37(5), pp. 1552-1559.

Breuer, T., M. Jandačka, J. Mencía and M. Summer. 2012. A systematic approach to multi-period stress testing of portfolio credit risk, *Journal of Banking & Finance*, Vol. 36(2), pp. 332-340.

Buncic, D. and M. Melecky. 2013. Macroprudential stress testing of credit risk: A practical approach for policy makers, *Journal of Financial Stability*, Vol. 9, pp. 347-370.

Cardarelli, R., S. Elekdagb and S. Lall. 2011. Financial stress and economic contractions, *Journal of Financial Stability*, Vol. 7, pp. 78-97.

Castro, V. 2013. Macroeconomic determinants of the credit risk in the banking system: The case of the GIPSI, *Economic Modelling*, Vol. 31, pp. 672-683.

Charles, A. and O. Darné. 2014. Large shocks in the volatility of the Dow Jones Industrial Average index: 1928-2013, *Journal of Banking & Finance*, Vol 43, pp. 188-199.

Chaudron, R. and J. de Haan. 2014. Dating banking crises using incidence and size of bank failures: Four crises reconsidered, *Journal of Financial Stability*, Vol. 15, pp. 63-75.

Chelluboina, B., V. Woo and W. Xoual. 2014. The Effectiveness of the Regulatory Stress Testing Disclosure Process, *Financial Markets, Institutions & Instruments*, Vol. 23(1). pp. 1-70.

Cohn, E. 1958. *Privatbanken i Kjøbenhavn gennem hundrede aar 1857-1957, II. halvbind: Efter arhundredeskiftet*, Copenhagen: Privatbanken i Kjøbenhavn.

Conant, C.A. 1915. *A History of Modern Banks of Issue*, Fifth Edition, New York: G.P. Putnam's Sons.

Danish Ministry of Business and Growth. 2013. *The financial crisis in Denmark – causes, consequences and lessons. Conclusions and recommendations*, Copenhagen: Schultz.

Dembiermont, C., M. Drehmann and S. Muksakunratana. 2013. How much does the private sector really borrow? A new database for total credit to the private non-financial sector, *BIS Quarterly Review*, March, pp. 65-81.

Dimsdale, N., S. Hills and R. Thomas. 2010. The UK recession in context – what do three centuries of data tell us?, *Bank of England Quarterly Bulletin*, Vol. 50(4), pp. 277-291.

Dovern, J., C.-P. Meier and J. Vilsmeier. 2010. How resilient is the German banking system to macroeconomic shocks?, *Journal of Banking & Finance*, Vol. 34(8), pp. 1839-1848.

Edvinsson, R., T. Jacobson and D. Waldenström (eds). 2010. *Historical Monetary and Financial Statistics for Sweden. Exchange rates, prices, and wages, 1277-2008*, Stockholm: Ekerlids Förlag.
Edvinsson, R., T. Jacobson and D. Waldenström (eds). 2014. *Historical Monetary and Financial Statistics for Sweden. Volume II: House Prices, Stock Returns, National Accounts, and the Riksbank Balance Sheet, 1620-2012*, Stockholm: Ekerlids Förlag.
Eichengreen, B. 2012. Economic History and Economic Policy, *Journal of Economic History*, Vol. 72(2), pp. 289-307.
Eitrheim, Ø. and S.K. Erlandsen. 2005. House prices in Norway 1819-1989, *Scandinavian Economic History Review*, Vol. 53(3), pp. 7-33.
Eitrheim, Ø., J.T. Klovland and J.F. Qvigstad, eds. 2004. Historical Monetary Statistics for Norway 1819-2003, *Norges Bank Occasional Papers*, No. 35.
Eitrheim, Ø., J.T. Klovland and J.F. Qvigstad, eds. 2007. Historical Monetary Statistics for Norway – Part II, *Norges Bank Occasional Papers*, No. 38.
ESCB Heads of Research. 2014. *Report on the macro-prudential research network (MaRs)*, Frankfurt: European Central Bank.
De la Escosura, L.P. 2014. Mismeasuring Long Run Growth: The Bias from Spliced National Accounts, *University of Warwick Working Paper Series*, No. 202.
Festic, M., A. Kavkler and S. Repina. 2011. The macroeconomic sources of systemic risk in the banking sectors of five new EU member states, *Journal of Banking & Finance*, Vol. 35, pp. 310-322.
Foglia, A. 2009. Stress testing credit risk: a survey of authorities' approaches, *International Journal of Central Banking*, Vol. 5(3), pp. 9-45.
Gaglianone, W.P. and R. Schechtman. 2012. Macro stress testing of credit risk focused on the tails, *Journal of Financial Stability*, Vol. 8, pp. 174-192.
Gerlach, S., M. Scatigna and S. Ramaswamy. 2006. 150 years of financial market volatility, *BIS Quarterly Review*, September, pp. 77-91.
Giesecke, K., F.A. Longstaff, S. Schaefer and I. Strebulaev. 2011. Corporate bond default risk: A 150-year perspective, *Journal of Financial Economics*, Vol. 102, pp. 233-250.
Giesecke, K., F.A. Longstaff, S. Schaefer and I. Strebulaev. 2014. Macroeconomic effects of corporate default crisis: A long-term perspective, *Journal of Financial Economics*, Vol. 111(2), pp. 297-310.
Glaeser, E.L. 2013. A Nation of Gamblers: Real Estate Speculation and American History, *American Economic Review*, Vol. 103(3), pp. 1-42.
De Haan, J., Z. Jing, J. Jacobs and H. Yang. 2015. Identifying banking crises using money market pressure: New evidence for a large set of countries, *Journal of Macroeconomics*, Vol. 43, pp. 1-20.
Haldane, A.G. 2009. *Why banks failed the stress test*, background paper for a speech given at the Marcus-Evans Conference on Stress-Testing, 9-10 February.
Hansen, P.H. 1996. *På glidebanen til den bitre ende. Dansk bankvæsen i krise 1920-1933*, Odense: Odense Universitets Forlag.
Hansen, P.H. and S. Mørch. 1997. *Den Danske Bank*, Copenhagen: Centrum.
Hansen, S.Aa. and K.E. Svendsen. 1968. *Dansk pengehistorie 1700-1914*, Copenhagen: Danmarks Nationalbank.
Halbeisen, P. and D. Maurer. 2007. Swiss National Bank Balance sheets and income statements, *SNB Historical Time Series*, Vol. 3.
Hoffmeyer, E. 1993. *Pengepolitiske problemstillinger 1965-1990*, Copenhagen: Danmarks Nationalbank.
Hoffmeyer, E. and E. Olsen. 1968. *Dansk pengehistorie 1914-1960*, Copenhagen: Danmarks Nationalbank.
Jones, B.F. and B.A. Olken. 2008. The Anatomy of Start-Stop Growth, *Review of Economics and Statistics*, Vol. 90(3), pp. 582-587.

Li, Q. and J.S. Racine. 2007. *Nonparametric Econometrics*, Princeton, NJ: Princeton University Press.

Marcucci, J. and M. Quagliariello. 2008. Is bank portfolio riskiness procyclical? Evidence from Italy using a vector autoregression, *Journal of International Finanacial Markets, Institutions and Money*, Vol. 18, pp. 46-63.

Mehl, A. 2013. Large global volatility shocks, equity markets and globalisation 1885-2011, *ECB Working Paper*, No. 1548.

Mikkelsen, R. 1993. *Dansk pengehistorie 1960-1990*, Copenhagen: Danmarks Nationalbank.

Mordhorst, K. 1968. *Dansk pengehistorie 1700-1960. Bilag*, Copenhagen: Danmarks Nationalbank.

Panetta, F. and R. Violi. 1999. Is There an Equity Premium Puzzle in Italy? A Look at Asset Returns, Consumption and Financial Structure Data over the Last Century, *Banca d'Italia Temi di discussione*, No. 353.

Reinhart, C.M. and K.S. Rogoff. 2009. *This time is different*, Princeton, NJ: Princeton University Press.

Riiser, M.D. 2005. House prices, equity prices, investment and credit – what do they tell us about banking crises? A historical analysis based on Norwegian data, *Norges Bank Economic Bulletin*, 3th Quarter, pp. 145-154.

Rosenfellner, R. and R. Wermelinger. 2009. Banks in Switzerland, *SNB Historical Time Series*, Vol. 5.

Rubow, A. 1920. *Nationalbankens historie 1878-1908*, Copenhagen: Nationalbanken i Kjøbenhavn.

Sayek, S. and F. Taskin. 2014. Financial crises: lessons from history for today, *Economic Policy*, Vol. 29(79), pp. 447-493.

Scatigna, M., R. Szemere and K. Tsatsaronis. 2014. Residential property price statistics across the globe, *BIS Quarterly Review*, September, pp. 61-76.

Schuermann, T. 2014. Stress testing banks, *International Journal of Forecasting*, Vol. 30(3), pp. 717-728.

Selz, B. 2007. Capital and stock markets, *SNB Historical Time Series*, Vol. 2.

Sorge, M and K. Virolainen. 2006. A comparative analysis of macro stress-testing methodologies with application to Finland, *Journal of Financial Stability*, Vol. 2, pp. 113-151.

Varotto, S. 2012. Stress testing credit risk: The Great Depression scenario, *Journal of Banking & Finance*, Vol. 36(12), pp. 3133-3149.