Staff Memo

Quantifying systemic risks with Growth-at-Risk

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Staff Memo

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Summary[1]

For a long time, there has been considerable interest in understanding and quantifying the link between changes in macro-financial conditions and economic growth. The focus has been on how macro-financial conditions affect the risk of sharply negative economic growth in the future, also known as downside risk. Understanding and quantifying this relationship is important because macro-financial conditions, as reflected in interest rates, asset prices and debts for example, can contribute to the accumulation of risks and vulnerabilities in the economy. In turn, these may affect the functioning of the financial system, especially when the economy is hit by a shock, and lead to the shock having a greater impact and a longer recovery period. This, in turn, increases the risk of lower economic growth in the future. In a financial crisis, where macro-financial risks are materialised, the losses can be both large and costly for the society with no certainty that the losses can be completely recouped.

The Riksbank works continuously to identify, analyse and communicate risks in the financial system, with the aim of promoting financial stability and preventing financial crises. This work is concerned with preventing the emergence of and reducing so-called *systemic risks,* and increasing resilience to the materialisation of such risks. Systemic risk is defined as the risk that a shock will occur in the financial system that could lead to substantial costs for society. This risk can be measured in different ways and its occurrence and development depend, among other things, on macro-financial conditions in the economy.

Using the risk measure *Growth-at-Risk*, the authors try to quantify the systemic risks. The authors find that changes in macro-financial conditions, through increased financial risks and vulnerabilities, entail higher downside risks for economic growth in Sweden in the future. When such risks and vulnerabilities are large enough, they can strengthen and prolong the effects on economic activity of a shock in the financial system. Described in more detail, the marginal effect of increasing financial risks and vulnerabilities on the downside risk of growth, the fifth percentile in GDP growth, is estimated to be at its highest after eight

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The staff memo covers developments up until the fourth quarter of 2021.

quarters, but will persist for up to twelve quarters, all other things being equal. The effect is about four times as high on the downside compared to the median, which indicates an asymmetrical and non-linear relationship between increased financial risks and vulnerabilities and future economic growth, as other studies also confirm for other countries.

It is important to continuously measure and monitor the risk of sharply negative economic growth as a result of changes in macro-financial conditions. This is because it lays out the ground for assessing and timely managing the vulnerabilities and conditions that could trigger a financial crisis and ultimately lead to a sharp drop in growth. *Growth-at-Risk* here forms a complement to the risk analysis surrounding the interaction between financial stability, macro-financial conditions and the real economy.

1 Introduction

1.1 Systemic risks can have serious consequences if they materialise

A crisis in the financial system often has major consequences for an economy. Companies go bankrupt, people become unemployed, and assets, both real and financial, often fall significantly in value, while government finances can deteriorate. In addition, it often takes a long time for the economy to recover and there is no certainty that the losses can completely be recovered. Although financial crises occur relatively rarely, they are a recurring part of history and have lasting and costly effects on society.

The Riksbank works continuously to identify, analyse and communicate risks in the financial system as a whole, with the aim of promoting financial stability and preventing financial crises. This work is concerned with preventing the emergence of and reducing so-called *systemic risks* and increasing resilience to the materialisation of such risks.[2] The probability of systemic risks materialising is small, but once it happens the effects can be severe. One challenge in safeguarding financial stability is to determine the extent of these effects. One method that can measure the size of systemic risks statistically is *Growth-at-Risk* (GaR). With the aid of GaR, we can form an idea of the risks of sharply negative outcomes for economic growth at various times in the future, using information on macro-financial conditions as a basis.

Background and purpose

This staff memo aims to complement the work that has already been conducted on GaR at the Riksbank by making the analysis more forward-looking.[3] Here, we therefore place greater emphasis on measuring the *marginal effect* that changed macro-financial conditions can have on *future economic growth*, with a particular focus on what happens if there are *sharply negative outcomes* in growth. We show that the marginal effect of increasing risks and vulnerabilities in the financial system has a significant negative impact on GDP growth eight to twelve quarters ahead. This effect is particularly prominent in the *fifth percentile* of the distribution of GDP growth, which is to say when GDP falls sharply. The results also suggest that systemic risks in the economy are higher now than before the outbreak of the coronavirus pandemic in 2020.

This Staff Memo has the following structure: First, we review the reasoning behind GaR as a method and its role in a wider economic context. We then present the data and model used in the estimations. The model and the data we use are largely the same as in Krygier and Vasi (2021) and the reader is referred to this publication for

[2] Systemic risk is usually defined as the risk that a shock will occur in the financial system that could lead to substantial costs for society. Such risks can arise for various reasons. See, for example, the publication "*The Riksbank and financial stability*", 2013, Sveriges Riksbank.

[3] See D. Krygier and T. Vasi (2021), "*Macrofinancial conditions, financial stability and economic growth in Sweden – evaluating the Growth-at-Risk framework*", Staff Memo, Sveriges Riksbank.

more details. We then review the results and also demonstrate how the estimates can be simply illustrated.

1.2 Systemic risks can be estimated using statistical methods

Growth-at-risk (GaR) is a method that attempts to quantify systemic risks from a statistical perspective.[4] The method takes its starting point in the risk measure *Value-at-Risk* (VaR) used to quantify the maximum drop in value of an investment with a certain probability and within a certain period of time. $VaR_{\alpha=95\%}^{1\,week}$ answers the question "*With a 95 percent probability, what is the maximum loss that can occur within one week?"* Formally, we can describe VaR as follows

$$\Pr(x_{t+h} \leq VaR_{\alpha}) = 1 - \alpha$$

where Pr denotes the probability of the term in brackets, x_{t+h} is the yield, VaR_{α} refers to the percentile of interest and the limit value of the maximum loss, and $1 - \alpha$ is the probability that the asset (the economic variable of interest) will not fall more in value than VaR_{α}. VaR is often used as a measure to calculate the risk of a change in the value of an asset when market conditions have changed. It is normally calculated on assets such as equities, where historical fluctuations in value are used to estimate the probability that the asset will decline in value by more than a specific amount over a specific period of time.[5]

Similarly, GaR signifies the maximum loss in terms of economic growth (GDP) that can, with a certain probability, occur over a specific period of time (*h*). However, since future economic development is not only dependent on how growth has developed in the past, the modelling of GaR is complemented by other variables.[6] For example, analysts often want to include something that reflects existing risks and vulnerabilities in the financial system, as these have proven to be relevant to economic growth. In practice, the maximum loss for growth at different times *t+h* is calculated given the status of macro-financial conditions at time *t*.[7] In this way, the effects of macro-financial conditions at a given time can be quantified, along with what they could 'cost' in terms of lower growth in the future. This makes GaR a relatively simple measure to understand. The formal equation for GaR can now be described as follows

[4] See Adrian et al. (2019) and the section "Method, applications and resultss".

[5] For a more thorough illustration of VaR, see page 16, section 5.1 of Krygier & Vasi (2021).

[6] For an equity price, it is often assumed that the best prediction model involves the share price tomorrow being determined by the share price yesterday plus an error term (a so-called random walk). This means that we do not have to involve any more variables in the estimation of VaR, since the variable's own history is assumed to contain enough information.

[7] *Financial conditions* describe the state of the financial markets and the interest rates, prices and conditions met by households and companies when they need to borrow or invest capital. *Vulnerabilities in the financial system* instead describe the inherent (and dynamic) risks that arise from the vulnerability of the system to disturbances and interconnected participants. This means that problems in one part of the system can easily spread to other parts. Taken together, we refer to *financial conditions* and *vulnerabilities in the financial system* as "*macro-financial conditions"* in this Staff Memo.

$$\Pr(x_{t+h} \leq GaR_{\alpha} | \Omega_t) = 1 - \alpha$$

in which Ω_t represents other available information that is assumed to affect the maximum loss, such as current financial conditions and various (inherent and growing) vulnerabilities in the financial system. Simply put, therefore, $GaR_{\alpha}|\Omega_t$ answers the question "*With a 95 percent probability, how much can GDP fall in the coming year (or other defined time period), given other information currently available, such as macro-financial conditions*?" Reversed, this means that the probability of a decline in value *greater than GaR* is 5 percent. As we are interested in the maximum loss with a probability of 95 percent, this means that GaR can be identified as the fifth percentile (1-0.95=0.05) of all outcomes (represented by an estimated conditional distribution) for the conditioned economic growth. All observations included up until the fifth percentile (the "tail") in the conditional distribution are to be regarded as extreme outcomes and illustrate systemic risks, which is to say outcomes that, if they materialise, may lead to substantial costs for society.

More information, Ω_t, in this case information on macro-financial conditions in the financial system, is added to the analysis because these conditions may affect economic development. For example, expansionary *financial conditions* have been shown to have a positive impact on economic growth in the short to medium term by increasing economic activity (see, for example, Adrian et al. (2018)). At the same time, expansionary financial conditions often mean that it is favourable for households and companies to borrow money, which, in the long term, means that debt is accumulating. Large debts that are also accumulated quickly can entail higher risks for financial stability and, if the risks materialise, economic growth (see Mian et al. (2017) for a longer discussion of this). If the financial system is vulnerable, the shocks that occur in the economy will be amplified while the recovery period will become longer (see, for example, Borio (2014), Brunnermeier and Sannikov (2014), Krishnamurthy and Muir (2017) and Claessens et al. (2011) for a description of this progression). The relationship and interaction between economic growth, financial conditions and financial risks and vulnerabilities is complex. Above all, this interaction has proved to be asymmetrical and non-linear. This is illustrated both in this and earlier studies. Methods such as GaR may thus be a useful tool in analysing this interaction. This Staff Memo investigates the asymmetry and non-linearity in a little more detail from a Swedish perspective.

2 Method, applications and results

2.1 Growth-at-Risk can be calculated using quantile regressions

When estimating GaR, as described in Adrian et al. (2019), the authors take the historical relationship between economic growth and financial conditions as a starting point before estimating the conditional probability distributions at different points within the period covered by the underlying data. In statistical terminology, this method of estimation is usually called an *in-sample fit*. The main point of estimating conditional probability distributions for GDP in a risk context is to demonstrate how the left-hand part of the distributions (often called the downside or "tail") changes over time alongside with macro-financial conditions changing and to show how well different parts of the conditional probability distribution can be explained. The authors find that the risk of a sharply negative outcome in GDP growth – *tail risk* or *downside risk* – correlates with developments in financial conditions. As these conditions in turn affect financial vulnerabilities, there may be a trade-off between financial vulnerabilities and future economic growth, meaning that increasing vulnerabilities increase the risk of low economic growth and vice versa. GaR can thus be seen as a way of quantifying how much growth may be lost.

In practical terms, GaR is modelled, both here and in Adrian et al. (2019), using quantile regressions, which evaluate the relationship in different *quantiles*, instead of just the mean value of the dependent variable as with ordinary OLS regressions.[8] This approach is taken because it tells us something about how macro-financial conditions affect economic growth not only "on average" (which can be translated approximately as during "normal times"), but also in times of crisis, such as when a shock hits the economy. If the financial system is vulnerable and systemic risks are considered elevated, a shock in the economy may lead to greater and more lasting negative effects than if systemic risks were initially assessed as relatively low, all other things being equal. The fact that the magnitude of the effects varies depending on whether the economy is in a crisis or not can be translated as meaning that the relationship between macro-financial vulnerabilities and economic growth is non-linear. Using quantile regressions, we can capture this non-linearity.

Another advantage of quantile regressions is that we can use the results to estimate the probability distribution of GDP growth as a whole, based on macro-financial conditions. This gives us an overview of possible outcomes for GDP and the associated probabilities. The poorer outcomes are then used to quantify the downside risks to GDP growth. Information about the properties of the probability distribution (such as the skewness and kurtosis of the distribution) and how these change over time also

[8] Quantiles are the points in a data set that divide the data set into a number of equal parts. If the data set is divided into 100 equal quantiles, with the same number of observations in each quantile, these parts are called *percentiles.* Percentile and quantile are used interchangeably in this Staff Memo.

provides additional information on the risks. This information is therefore useful in the risk analysis.

Throughout this Staff Memo, we use the Riksbank's indicator of financial risks and vulnerabilities, the *systemic risk indicator*, to describe the macro-financial conditions in the financial system.[9] However, these can be measured in more ways and with other indicators.[10] One alternative is to use the Riksbank's *index for financial conditions*.[11] The results of estimates made with this index are shown in the Appendix. However, the conclusions that can be drawn on GaR and the risk outlook are similar. The model estimated in this Staff Memo is similar to that estimated by Adrian et al. (2019) but supplemented by projections of GDP growth a number of quarters ahead. In the next section, we describe the model and estimates in more detail.

2.2 Model specification and description of data

The dependent variable consists of GDP growth as an annual percentage change at a quarterly frequency, while the explanatory variables consist of the systemic risk indicator and GDP growth lagged one period. A simple illustration of the relationship we want to estimate is as follows:

$$\Delta BNP_{t+h} = f(SRI_t, \Delta BNP_{t-1}) \tag{1}$$

where ΔBNP_{t+h} constitutes GDP growth in quarter *t+h*, SRI_t constitutes the systemic risk indicator in quarter *t* and ΔBNP_{t-1} is GDP growth in quarter *t-1*.

The estimation of the projections is based on the *local projections* method (Jordá (2005))[12]. The following regressions are estimated for each quantile:

$$\widehat{\beta_{h,q}} = \underset{\beta_{h,q}}{\operatorname{argmin}} \sum_{t=1}^{T-h} \Big(q \cdot \mathbf{1}\big(y_{t(p)+h} \geq x_{t(p)}\beta_{h,q}\big)\big|y_{t(p)+h} - x_{t(p)}\beta_{h,q}\big| + (1-q) \cdot \mathbf{1}\,\big(y_{t(p)+h} < x_{t(p)}\beta_{h,q}\big)\big|y_{t(p)+h} - x_{t(p)}\beta_{h,q}\big| \Big) \tag{2}$$

where $\mathbf{1}_{(.)}$ is an indicator function, $y_{t(p)+h}$ is the GDP growth *h* periods in the future, $x_{t(p)}$ represents our explanatory variables (the systemic risk indicator and the previous period's GDP growth as control variable), *q* stands for quantiles (percentiles), and *p* stands for projection. The estimated value of the regression given $x_{t(p)}$ for quantile *q* is:

[9] The systemic risk indicator is intended to illustrate systemic risks on an overall level by assessing vulnerabilities and risks in the banking sector, household sector, non-financial corporate sector and property market, as well as outside of the financial system (denoted 'the external environment'). For a more detailed description of the systemic risk indicator, see Krygier and van Santen (2020).

[10] For example, the ECB (2021) uses two types of indicators to describe the macro-financial conditions: an index for financial conditions and an index for financial stress.

[11] See J. Alsterlind et al. (2020), "*An index for financial conditions in Sweden*", Staff Memo, Sveriges Riksbank.

[12] The method can be compared to a VAR model, but some underlying dynamic assumptions do not need to be met using *local projections.* See details in Jordá (2005).

(3) $$\hat{Q}\left(y_{t(p)+h|x_t}|x_{t(p)}\right) = x_{t(p)}\hat{\beta}_{h,q}$$

Equation 3 thus shows the estimated *projected* outcome at quantile *q* given the systemic risk indicator at *t*. The quantiles *q* included are 5, 10, 15 and so on, up to and including the 95th quantile. The projection is made for time horizons of 1 to 12 quarters.

The results from the quantile projections are then used to estimate the conditional probability distribution for GDP growth using a skewed *t*-distribution (see Appendix in Krygier and Vasi (2021) for details). By describing the conditional GDP growth with a distribution, we can use it to find probabilities for GDP growth to be within a certain range, given the development of the systemic risk indicator. Although we estimate the entire distribution, the lower estimated percentiles are more interesting from a systemic risk perspective than, for example, the median or higher percentiles, since we want to estimate the costs of sharply *negative* real economic outcomes. These outcomes are often far from the median. The fifth percentile is normally appropriate as a measure to illustrate the risks and it is this percentile that constitutes the estimate of GaR. In this way, quantile coefficients help us get a picture of the non-linear relationship between macro-financial conditions and GDP growth.

It is important to emphasise that we do not estimate any *causal effects*, but only the forecasting value of the current level of the systemic risk indicator on future GDP growth.[13] Overall, the model illustrates downside risks and GDP growth in times of crisis.

Data – Swedish GDP and the Riksbank's systemic risk indicator

As mentioned above, the analysis uses two main variables: the annual growth rate for GDP and the Riksbank's systemic risk indicator. Both variables use a quarterly frequency and the study period ranges from the first quarter of 1982 to the fourth quarter of 2021. Chart 1 shows the development of the variables and Table 1 summarises descriptive statistics for the time series.

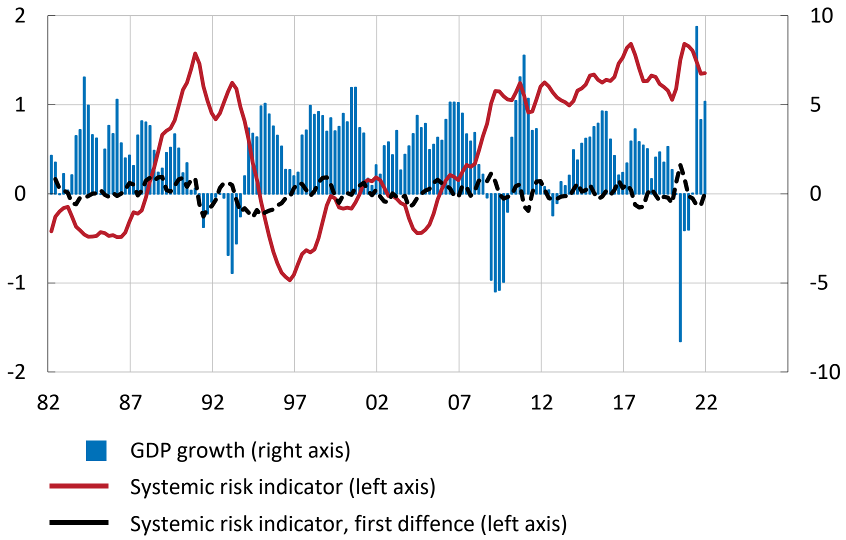
For GDP, three distinct periods of negative growth are shown: the crisis of the 1990s in Sweden, the global financial crisis of 2008-2009 and the coronavirus pandemic. The average annual growth rate was slightly more than 2 per cent during this period. In the fifth percentile, GDP growth is about -2.5 per cent, while the largest GDP fall in the series (*min)* is -8.28 per cent. Over the last two decades, the systemic risk indicator, standardised and expressed in standard deviations from its average value, has shown that risks and vulnerabilities are increasing in the financial system. At the end of the 1980s, the indicator rose very quickly as a result of the economic problems that Sweden was suffering. The deregulation of the credit market and the increased borrowing also contributed to a subsequent banking and financial crisis in the early 1990s, which caused a major decline in economic growth. Between 2005 and up until the global financial crisis, the systemic risk indicator again showed that risks and vulnerabilities had increased in the financial system. Since then, the level of the indicator has been relatively stable, but high in terms of the mean value of 0.45.

[13] We cannot rule out that GDP also affects systemic risks in the economy.

Overall, GDP growth varies more than the systemic risk indicator. However, by only examining how the variables develop in the chart below reveals that falls in GDP growth tend to coincide with increases in the systemic risk indicator. The correlation between the variables is calculated at -0.36 and is statistically significant at a one-per-cent level.

Chart 1. GDP growth and the systemic risk indicator

Percentage and standard deviation from mean value



Note. GDP growth is expressed as an annual percentage change at a quarterly frequency (right axis). The systemic risk indicator is expressed as deviations from the mean value (standard-ised). The series' first difference is also plotted (left axis). For more information on the indica-tor, see Krygier and van Santen (2020).

Sources: Statistics Sweden and the Riksbank.

Table 1. Descriptive statistics for input variables

Percentage and standard deviation from mean value

Measure	GDP growth	Systemic risk indicator
Mean	2.20	0.45
Median (50th percentile)	2.68	0.34
Standard deviation	2.53	0.76
Min	-8.28	-0.96
Max	9.38	1.68
5th percentile	-2.09	-0.65
95th percentile	5.23	1.50

Note. *N*=161. Figures are for the period Q1 1982 to Q4 2021. The systemic risk indicator is expressed in the unit standard deviation from mean value (values can therefore be negative). GDP growth is expressed as an annual percentage change. The standard deviation of the systemic risk indicator is less than one due to a shorter part of the indicator being used in the estimations.

Sources: Statistics Sweden and the Riksbank.

Over the last 15 years, the systemic risk indicator has generally shown an upward trend. This can partly be linked to structural problems in the Swedish financial system that have contributed to vulnerabilities for a long time. The systemic risk indicator does not distinguish between structural and cyclical systemic risk apart from the data processing carried out (for example filtering and standardisation of variables). Consequently, it is not possible to rule out the absence of a trend factor in the systemic risk indicator, even though it considers this to some extent in its design. In econometric terms, this indicates that the systemic risk indicator may be *non-stationary*. This means that the statistical inference may be misleading with deceptive R^2values and *t*-statistics, among other things, which could lead to erroneous conclusions being drawn.[14] To test if the systemic risk indicator is non-stationary, we use the *Dickey-Fuller* test. This tests the null hypothesis that the variable in question has a so-called unit root and is therefore considered non-stationary. Such a test on the systemic risk indicator will result in a rejection of the null hypothesis at the ten per cent level. To ensure that the variable is stationary, we transform the variable in the first differential form before we make the econometric estimates.[15] This is a common transformation of economic data used to manage non-stationarity, but it makes the interpretation of results more difficult and it is therefore *not* used in the estimations and results that follow next.

2.3 Results

There is a non-linear relationship between macro-financial conditions and economic growth

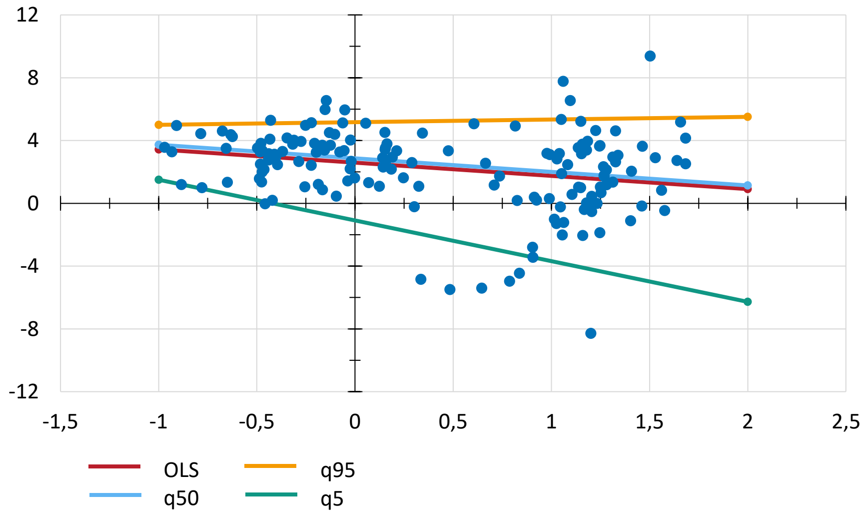
The results of the regressions and projections are presented here in the form of coefficients for different percentiles and time horizons. However, we start by plotting our two variables in a scatter plot to get an idea of the relationship between them, historically speaking. Each blue dot in Chart 2 represents an outcome of GDP growth (Y-axis) and the corresponding outcome for the systemic risk indicator (X-axis). The clustered points indicate that higher values in the systemic risk indicator are generally associated with slightly lower values for GDP growth and vice versa. At the same time, a slightly higher spread can be observed in the right-hand cluster than in the left-hand one.

[14] A stationary series fluctuates around a constant value or trend (variance and mean value are constant over time).

[15] The results with the SRI expressed in the first differential are not significantly different from the results with a level SRI. The same conclusions can be drawn on the relationship between GDP growth and the systemic risk indicator.

Chart 2. Scatter plot with associated regression lines for different quantiles

Percentage change (GDP), standard deviations from mean value (SRI)



Note. The figure shows a scatter diagram for GDP growth two years ahead (Y-axis) and the systemic risk indicator now (X-axis). The lines show the estimated relationship of variables in different quantiles with GDP growth as dependent variable. The red line is based on a univariate OLS regression and the other lines are based on univariate quantile regression at the quantiles *q*= 5, 50 and 95. The following equation is estimated $BNP_{t+8}^{q} = \alpha^{q} + \beta^{q} SRI_{t}^{q} + \varepsilon^{q}$ for *q*=[5, 50, 95] and the corresponding OLS variant. Even when the most extreme observations are removed, the relationship is significant.

Sources: Statistics Sweden, the Riksbank and the authors' own calculations.

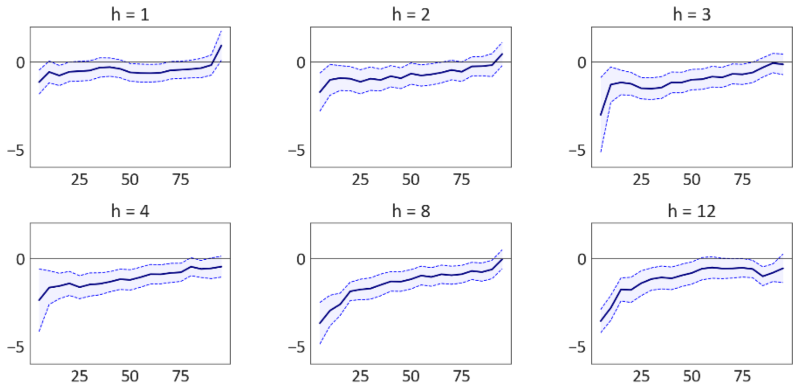
By estimating (univariate) linear regressions and plotting the estimated trend lines in the scatter plot, we can also see that the slope of the lines, which is to say the relationship between GDP growth and the systemic risk indicator, tends to differ depending on whether GDP growth is very low (fifth quantile) or very high (95th quantile). In Chart 2, we can note that the relationship in the fifth quantile (green line) is stronger than the relationship in the median (light blue line) or in the 95th quantile (orange line). The fifth quantile of GDP growth (downside risk) has a negative relation to rising risks and vulnerabilities in the financial system (represented by the systemic risk indicator), as shown by the negative slope of the green line. The lines of the other quantiles (except for the 95th percentile, where the slope is slightly positive) and of the OLS estimate (mean value) are negative, but not as much. The fact that the relationship differs between different quantiles shows that the relationship between risks and vulnerabilities in the financial system and economic growth is non-linear and, by extension, that high and increasing risks and vulnerabilities may lead to greater risks of negative economic growth in the future.

Economic growth is adversely affected by high and rising financial risks and vulnerabilities

In Chart 3, we show, as a second step, the marginal effects of increasing financial risks and vulnerabilities (represented by the systemic risk indicator) on GDP growth for up to three years (12 quarters) into the future with the associated confidence interval of 95 per cent. The model estimated here is the one presented in section 2.2 (equation

2). The marginal effect shows how GDP growth, in percentage points, is affected by a one standard deviation increase in the systemic risk indicator. From a systemic risk perspective, we are interested in the downside risk, which is to say the effect in the fifth percentile (compare with the green line in Chart 2). However, the point of showing the coefficients (the effect) for different quantiles, not just the fifth, is to illustrate that the relationship between the systemic risk indicator and GDP growth is non-linear. The strength of the relationship also varies depending on which time horizon we are looking at, in accordance with the concept that vulnerabilities affect GDP growth with a time lag.

Chart 3. Estimated quantile coefficients for SRI for different time horizons, *h*
Percentage points



Note. The chart shows the estimated coefficients of the SRI variable for different time horizons. The horizontal axis shows percentiles. One time horizon in the future (*h*=1) stands for one quarter in the future. The dashed lines show a confidence interval of 95 per cent. Note that the systemic risk indicator is standardised and expressed in standard deviations from its mean value.

Source: Authors' own calculations.

The results in Chart 3 show several things. If we look at the marginal effect at the 50th percentile, which corresponds to the median relationship between GDP growth and the systemic risk indicator, it is significantly negative in both the short term and the longer term. The marginal effect averages about -1 percentage points, seen over all time horizons. The effect is strongest on the time horizons of four and eight quarters, after which it declines.[16]

Instead, if we look at the marginal effect at the fifth percentile (furthest to the left in the figures of Chart 3), which instead corresponds to the tail risk or the risk of a sharply negative outcome, it is also significantly negative. In particular, the marginal effect is more negative than it is at the higher quantiles, which indicates that the effect of elevated risks and vulnerabilities correlates more strongly with negative GDP outcomes. Put simply, higher risks and vulnerabilities in the financial system are estimated to increase the probability of a sharply negative outcome for GDP in the future,

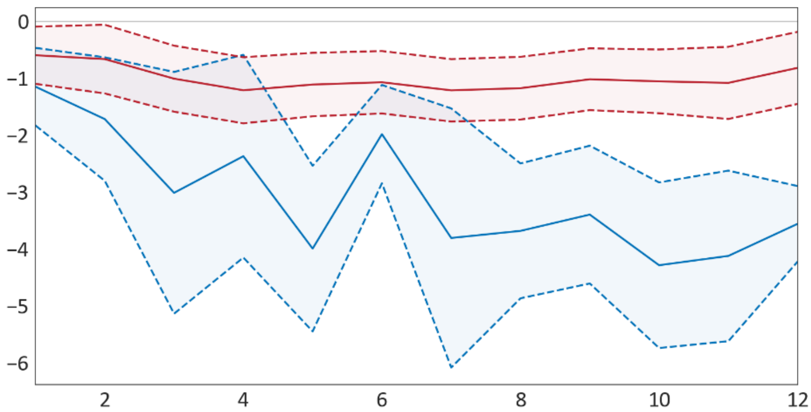
[16] This is illustrated by the fact that the solid line, with the associated 95 per cent confidence interval, is below the zero line at value 50 on the horizontal axis.

all other things being equal. The marginal effect is noticeable and significant for different time horizons, but is most substantial eight quarters ahead. This means that increased risks and vulnerabilities most strongly increase the probability of highly negative outcomes for GDP two years ahead. The tail effect is estimated at about -4 percentage points over a time horizon of 2 years. This is more than the fifth percentile in GDP growth (actual outcomes) in the period 1982-2021 (see Table 1). Furthermore, our results for a four-quarter time horizon are consistent with the empirical observation that increasing financial imbalances primarily affect the tail risk for GDP growth in the medium to long term and not directly, as is the case, for example, with the effects of financial stress or financial conditions on GDP growth.[17] These results hold true even when we remove outliers from the data sample, although they become slightly less negative.

In Chart 4, we look more closely at the marginal effect of just the fifth and 50th quantiles (median) and show how they develop over time. In other words, we plot the quantile projection for the fifth and 50th percentiles that show the marginal effect in the median and tail on GDP growth if the systemic risk indicator were to increase by one unit.[18] The horizontal axis, which runs from 1 to 12, indicates the number of quarters since the increase in the SRI occurred. The marginal effect on GDP growth is visible in the vertical axis. Since the parameters of the model depend on duration and are therefore different every quarter, the effect is different at each point in time.

Chart 4. Estimated marginal effect of SRI on GDP growth

Percentage points



Note. The lines illustrate the marginal effect of the SRI *h* quarters ahead on GDP growth (compare with the impulse response of a standard deviation's increase). The estimates are based on local projection estimates (Jordá (2005)). The red line represents the marginal effect in the median of the SRI on GDP growth, while the blue line shows the marginal effect of the SRI on the fifth percentile of GDP growth. The red and blue dashed lines make up a 95-per cent confidence interval.

Source: Authors' own calculations.

[17] See, for example, Adrian et al. (2018), IMF (2017), Adrian et al. (2019) and Aikman et al. (2019). See also the results in the Appendix, where the Riksbank's index for financial conditions is included in the model instead of the systemic risk indicator.

[18] Note that the systemic risk indicator is standardised so its unit is "standard deviations from the mean".

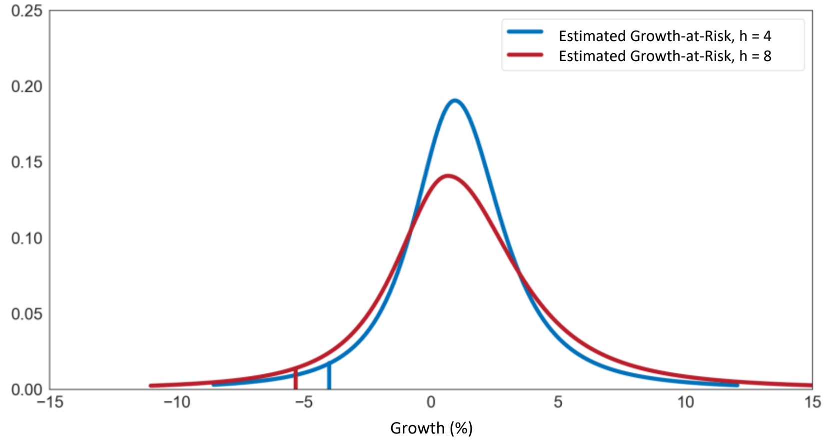
The chart illustrates that, up to the fourth quarter, there is no significant difference in the effect on the median and tail, as can be seen by the way the solid lines with associated confidence intervals overlap each other. However, the actual marginal effect on GDP growth is statistically significant since the solid lines, with associated confidence intervals, are below the zero line. If we move to the right in the chart and increase the time horizon, we see that the difference in effect is significant from eight up to twelve quarters ahead, and that the effect on the median and tail is beginning to diverge. By the eighth quarter, there is a 95 per cent probability that the worst outcome for GDP growth (the GaR estimate) has increased by about -4 percentage points, while the median effect on GDP growth is about -1 percentage point. In other words, the marginal effect is about four times greater in the tail than in the median value of GDP growth. It is difficult to say whether this is a big difference but previous studies find a difference of about the same magnitude between the two effects. Our conclusion, therefore, is that an increase in the SRI increases the downward risk for GDP growth in the long term (= eight to twelve quarters) but not by very much in the near term. Here too, we can demonstrate the non-linear relationship between GDP growth and the systemic risk indicator.

Estimates of conditional probability distributions for future economic growth illustrate the risks

In a final step, Chart 5 shows the entire conditional probability distribution for GDP growth four and eight quarters ahead respectively, estimated using data up to quarter 4 2021. The chart shows that the eight-quarter time horizon distribution is flatter and the estimated value of GaR is to the left of the corresponding point in the distribution for a four-quarter time horizon. We know from our results in Chart 3 and Chart 4 that the marginal effect shown by the systemic risk indicator on GDP growth is strongest after eight quarters. Consequently, it is reasonable that the conditional probability distribution for an eight-quarter forecast horizon is slightly more to the left and is flatter than the probability distribution for four quarters ahead. This effect can be seen in Chart 5 where GaR becomes more negative two years ahead (h=8), everything else equal, comparing to one year ahead (h=4). In addition, the distribution two years ahead is somewhat shifted to the left. One year ahead, this is reversed. Our results confirm our earlier conclusion that the vulnerability of the economy to shocks and the materialisation of highly negative outcomes affect growth up to two years ahead, all other things being equal.

Chart 5. Estimated distribution of GDP growth for four and eight quarters ahead

Frequency



Note. The figure shows the probability distributions for GDP growth four (*h*=4) and eight (*h*=8) quarters ahead estimated using data up to the most recent outcome for the systemic risk indicator and GDP growth (Q4 2021). The probability distributions are estimated using quantile projections. The vertical lines mark GaR (the fifth percentile in the distributions).

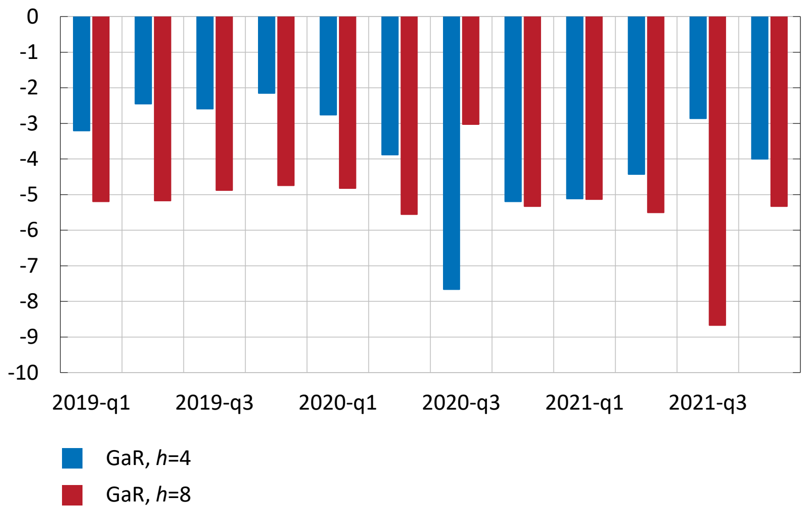
Source: Authors' own calculations.

Tail risks vary over time and differ depending on the time horizon

In Chart 6, we instead show the GaR estimate (the fifth percentile) over time starting in Q4 2018. The bars thus show what the model says about the tail risk for growth four and eight quarters ahead, given the current macro-financial conditions (the systemic risk indicator) and the previous quarter's GDP growth at the different time points shown by the horizontal axis. The value of the bar thus corresponds to the 95 per cent probable maximum decrease in GDP growth over a period of four (blue) and eight (red) quarters. This illustration gives us an idea of how changes in macro-financial conditions and dynamics in GDP growth over time affect the tail risk for GDP growth.

Chart 6. Estimated Growth-at-Risk over time four and eight quarters ahead

Per cent



Note. The graph shows the Growth-at-Risk estimate four and eight quarters ahead with a starting point in the times shown on the horizontal axis. For example, for December 2018, the tail risk (GaR, fifth percentile) is estimated four and eight quarters ahead, that is the estimated tail risk for Q4 2019 and Q4 2020. The estimate of GaR is thus interpreted as the 95 per cent probable maximum negative growth for GDP four and eight quarters in the future from time *t*, today (horizontal axis).

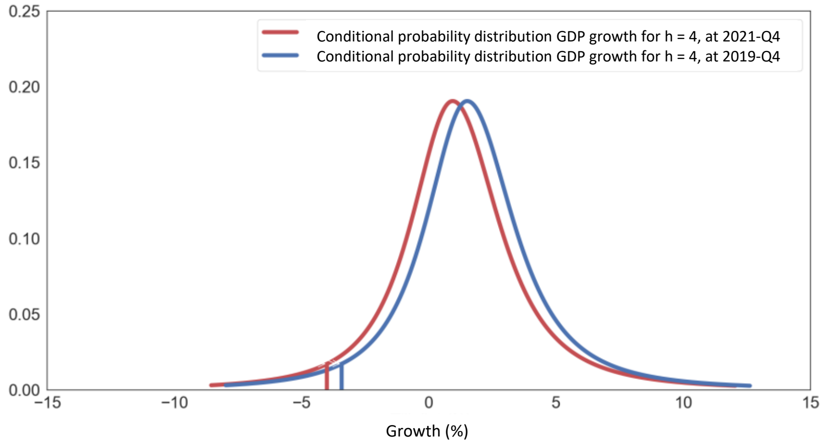
Source: Authors' own calculations.

In Chart 7 we compare two points in time – the fourth quarters of 2019 and 2021, respectively, using the latest outcomes. The comparison illustrates how the assessment of risks one and two years ahead has changed between the two periods. During this period, fluctuations in the Swedish economy have been greater and faster than usual as a result of the unusual effects of the coronavirus pandemic, which has increased the volatility of the explanatory variable, GDP growth (see also Chart 14 in APPENDIX – Additional figures). At the same time, the level of the systemic risk indicator has risen. However, the difference between the fourth quarter of 2019 and the fourth quarter of 2021 is small, as the indicator initially increased in 2020 but subsequently dropped from its temporary peak during the pandemic.

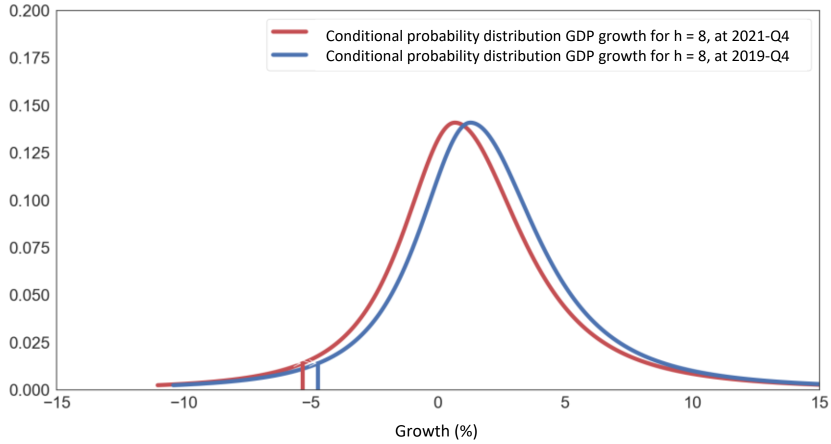
Chart 7. Estimated distribution of GDP growth four and eight quarters ahead

Frequency

Panel A: *h= 4*



Panel B: *h = 8*



Note. The figure shows the probability distributions for GDP growth for four (*h*=4) and eight (*h*=8) quarters ahead given data up to Q4 2021 and to Q4 2019. The probability distributions are estimated using quantile projections. GaR is estimated for each point in time and is marked by vertical lines in the distributions.

Source: Authors' own calculations.

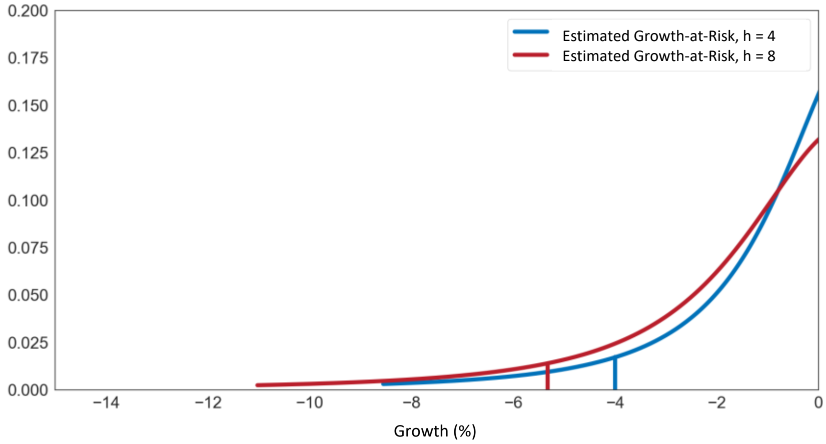
According to Chart 7, the estimate of tail risk, GaR, measured as the fifth percentile in the probability distribution, has increased marginally compared with the outlook for Q4 2019, which is to say before the pandemic. The estimate of GaR has increased from approximately -2.2 per cent (-4.8) to -4 percent (-5.4) in four (eight) quarters of the time horizon between Q4 2019 and Q4 2021. However, it is not only the actual GaR estimate that has increased. The probability distribution as a whole has become somewhat flatter. In other words, more probability mass has been allocated in both the right and left tail – probably because economic development has been very volatile in 2021.

The results of the GaR estimates can be visualised in different ways

Recently, GaR has increasingly been used by central banks and international organisations in their communication concerning financial stability risks. For example, the IMF introduced a GaR-based analysis into its Stability Report in 2017.[19] There are several ways of visualising GaR. In general, the entire conditional distribution of GDP growth is illustrated at different points in time and, in this, estimated GaR is marked in the distribution in a similar manner to the estimated distributions in Chart 5 and Chart 7. Another option is to focus only on the left-hand part of the distribution and thus obtain a better overview of the left-hand tail and the approximate GaR estimate (see Chart 8 as well as Chart 6).

Chart 8. The left-hand part of the estimated distribution of GDP growth four and eight quarters ahead

Frequency



Note. The figure shows the left-hand part of the probability distributions for GDP growth four (*h*=4) and eight (*h*=8) quarters ahead at Q4 2021. The probability distributions are estimated using quantile projections. The vertical lines mark GaR (the fifth percentile in the distributions) and amount to -4 per cent one year ahead (*h*=4) and -5.7 per cent two years ahead (*h*=8).

Source: Authors' own calculations.

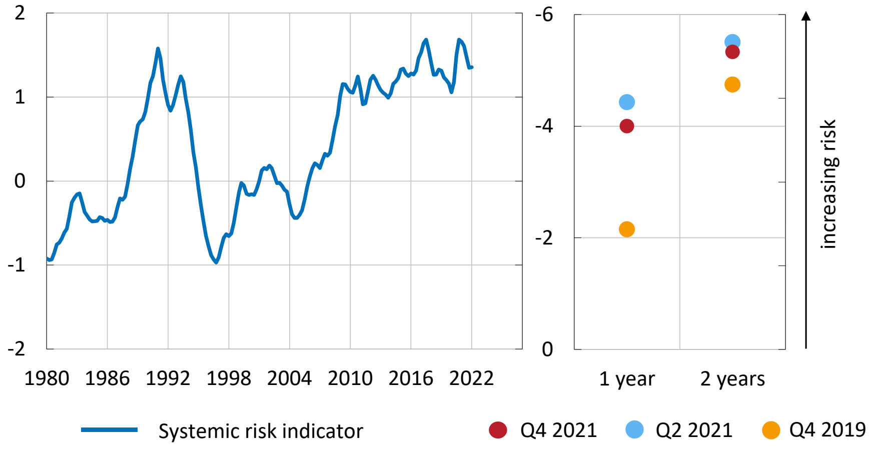
A third option showing the combination of the development of the systemic risk indicator and GDP growth with the GaR estimate is presented in Chart 9. Here we focus only on a few GaR estimates at different times. The narrower figure to the right is inverted to associate points higher up with increasing risks, as with the systemic risk indicator (left) where a higher value also indicates increasing risks and vulnerabilities. The ECB makes a similar visualisation of GaR in its Stability Review.[20] GaR, which is initially expressed as a percentage in the form of a decline in value, can also be translated into a decline in value in kronor. The negative return is simply multiplied by, for example, the monetary value of GDP over a year.

[19] *Global Financial Stability Report, 2017: Is Growth at Risk*, October 2017, IMF.

[20] Chart 1, page 5 of *Financial Stability Review*, October 2021, European Central Bank.

Chart 9. The Riksbank's systemic risk indicator and *Growth-at-Risk* estimates

Deviation from mean value, per cent



Note. Left: A higher value means higher risks and vulnerabilities. For all series included, see D. Krygier and P. van Santen (2020), "A new indicator of risks and vulnerabilities in the Swedish financial system", Staff memo, Sveriges Riksbank. Right: Estimate of the fifth percentile (GaR) in the predictive distribution of GDP growth 1 and 2 years ahead, respectively.

Sources: Authors' own calculations and the Riksbank.

3 Conclusion - Financial risks and vulnerabilities have a negative impact on economic growth

The purpose of this staff memo has been to show how macro-financial conditions can affect risks linked to future economic growth in Sweden. We have shown this by estimating the ratio between GDP growth and the systemic risk indicator at different quantiles and then projecting the estimated marginal effect of up to twelve quarters. The aim of the projection is to study how the whole conditional distribution of GDP growth is affected and how the tail risk, defined as Growth-at-Risk, is affected. The tail risk corresponds to the fifth percentile of the GDP growth distribution and describes sharply negative outcomes.

The results indicate that high and increasing risks and vulnerabilities in the financial system have a significantly negative impact on GDP growth in the medium term (eight to twelve quarters) and especially in the fifth percentile of the GDP growth distribution. The marginal effect here is about four times the marginal effect in the median. From a financial stability perspective, the downside risk is important to analyse, as it gives us an idea of the costs that a financial crisis could entail for the real economy.

When we study the distributions on different time horizons, we can see that they often vary over time, depending both on the outcome of the systemic risk indicator and on how actual GDP develops. In addition, the GaR estimate for a longer time horizon (eight to twelve quarters) is almost always more negative than the estimate for four quarters. This has to do with an increase in uncertainty – more things can happen in eight quarters than in four. Increasing financial risks and vulnerabilities also have a slight lag in the impact on the tail risk, a finding that is confirmed in other studies as well.

Finally, regarding the risks ahead, we illustrate how the GaR estimate has changed over the past two years and what it looks like today, Q4 2021. Compared to the fourth quarter of 2019, i.e. before the pandemic started in Europe and Sweden, the GaR was estimated to be about -2.2 per cent one year ahead and -4.8 two years ahead. This is interpreted as GDP growth will not fall by more than -2.2 per cent in the coming year with a 95 per cent probability (-4.8 in the next two years) given a shock and given the level of the systemic risk indicator (then, Q4 2019, at 1.05, see Chart 1). In 2020, the economy was affected by a major shock in connection with the outbreak of the coronavirus. It is important to remember that this shock did not originate in the financial system, but the initial status of macro-financial conditions probably played a role in the size of the real economic costs resulting from the coronavirus pandemic. If we compare it with a slightly later date, the GaR estimate in Q2 2021 is instead -4.4 percent (one year ahead) and -5.5 percent (two years ahead). This increase in GaR is primarily due to the fact that we had a sharp fall in GDP and secondly to the fact that the systemic risk indicator also rose relatively substantially between the two periods (see Chart 14). The view at the latest observation that the staff memo covers, Q4 2021, is that the tail risk is higher both one and two years ahead (-4 and -5.4 percent respectively, see Chart 6 and Chart 8) compared to the assessment in Q4 2019, but marginally lower than the estimate in Q2 2021. However, the use of GaR to evaluate the risk picture *during and as a result of the coronavirus pandemic* should be interpreted with some caution. This is because the crisis during the pandemic was unusual, while economic growth recovered very quickly and strongly. Unlike previous financial and economic crises that have left a more or less permanent dip in a country's growth, the sequence of events during the coronavirus pandemic is different from previous crises. The results in the staff memo as a whole correspond well with the wider empirical GaR literature.

The continuous measurement of systemic risks using GaR can be an additional tool in the analysis of financial stability. Monitoring the development of the risks of sharply negative economic outcomes is important as it can lay the ground for assessing and managing vulnerabilities and conditions that could cause a financial crisis in the future. Here, GaR is a complement to the risk analysis, where a statistical approach is linked to economic theory about the interaction between financial stability, macro-financial conditions and the real economy.

References

Adrian, T., Boyarchenko, N., & Giannone, D. (2019). Vulnerable growth. American Economic Review, 109(4), 1263-89.

Adrian, T., Grinberg, F., Liang, N., & Malik, S. (2018). The term structure of growth-at-risk. International Monetary Fund.

Aikman, D., Bridges, J., Hacioglu Hoke, S., O'Neill, C., & Raja, A. (2019). Credit, capital and crises: a GDP-at-Risk approach.

Borio, C. E., & Lowe, P. W. (2002). Asset prices, financial and monetary stability: exploring the nexus.

Brunnermeier, M. K., & Sannikov, Y. (2014). A macroeconomic model with a financial sector. American Economic Review, 104(2), 379-421.

Claessens, S., Ghosh, S. R., & Mihet, R. (2013). Macro-prudential policies to mitigate financial system vulnerabilities. Journal of International Money and Finance, 39, 153-185.

Claussen, C. A. (2013). Are Swedish houses overpriced?. International Journal of Housing Markets and Analysis.

IMF (2017), Is growth at risk?, Global Financial stability Report 2017.

Jonung, L. (2019). Ekonomiska kriser och krisberedskap i Sverige [Economic crises and crisis preparedness in Sweden].

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. American Economic Review, 95 (1), 161-182.

Jordà, Ò., Schularick, M., & Taylor, A. M. (2013). When credit bites back. Journal of Money, Credit and Banking, 45(s2), 3-28.

Krishnamurthy, A., & Muir, T. (2017). How credit cycles across a financial crisis (No. w23850). National Bureau of Economic Research.

Krygier, D & van Santen, P. (2020), A new indicator of risks and vulnerabilities in the Swedish financial system, Staff Memo, Sveriges Riksbank.

Krygier, D & Vasi, T. (2021), Macrofinancial conditions, financial stability and economic growth – evaluating the GaR framework, Staff Memo, Sveriges Riksbank.

Mian, A., Sufi, A., & Verner, E. (2017). Household debt and business cycles worldwide. The Quarterly Journal of Economics, 132(4), 1755-1817.

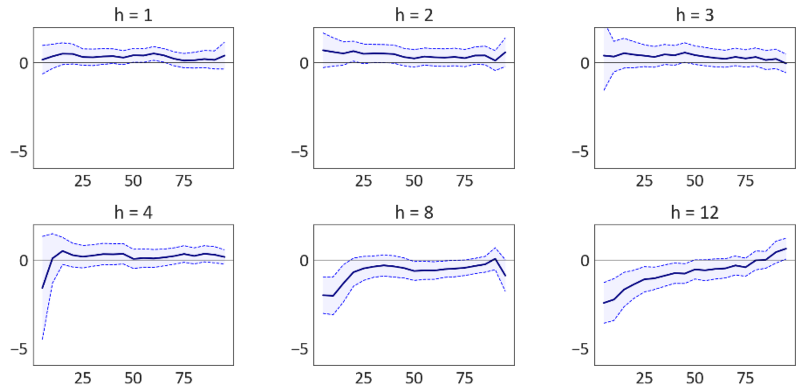
Schularick, M., & Taylor, A. M. (2012). Credit booms gone bust: Monetary policy, leverage cycles, and financial crises, 1870-2008. American Economic Review, 102(2), 1029-61.

APPENDIX – Results with the Riksbank's Financial Conditions Index (FCI)

Below are the results of an estimation exercise where the Riksbank's Financial Conditions Index (FCI) is used as an explanatory variable instead of the systemic risk indicator (SRI). 'Financial conditions' is a broad concept that is often used to summarise the state of financial markets and the interest rates, prices and terms that households and companies face when borrowing or investing capital. In contrast to the systemic risk indicator, no explicit indicators of, for example, indebtedness and systemic risk are therefore included. Read more about the Financial Conditions Index in Alsterlind, Lindskog and von Bammsen (2020), "*An index for financial conditions in Sweden*", *Staff Memo,* Sveriges Riksbank.

Chart 10. estimated quantity coefficients for FCI for different time horizons *, h*

Percentage points

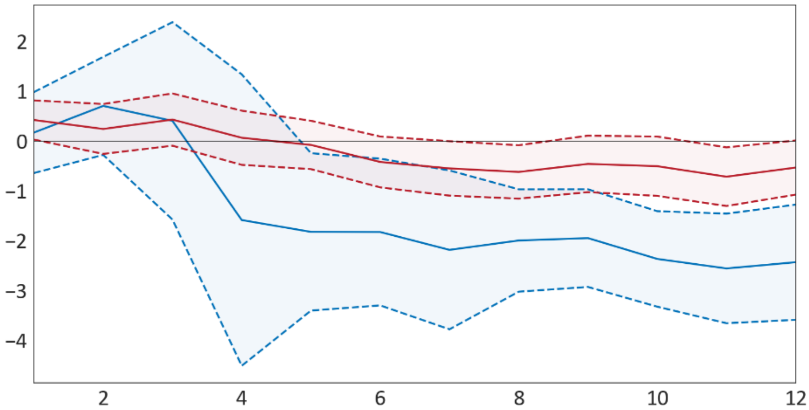


Note. The figures show the estimated coefficients of the FCI variable for different time horizons. The horizontal axis shows percentiles. A time horizon in the future (h=1) stands for one quarter in the future. The dashed lines show a confidence interval of 95%.

Source: Authors' own calculations.

Chart 11. Estimated marginal effect of FCI on GDP growth

Percentage points

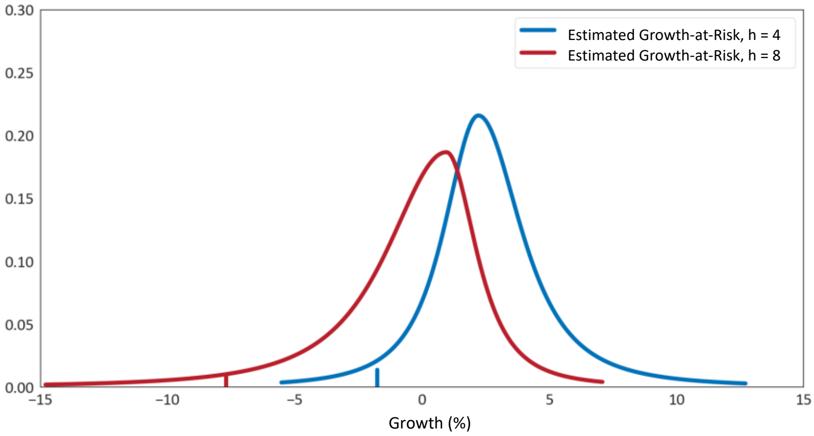


Note. The lines illustrate the marginal effect of FCI *h* quarter ahead on GDP growth (impulse response of a standard deviation's increase). The estimates are based on *local projection estimates* (Jordá (2005). The red line represents the marginal median effect of FCI on GDP growth, while the blue line shows the marginal effect of FCI on the fifth percentile. The red and blue dashed lines are 95-per cent confidence intervals.

Source: Authors' own calculations.

Chart 12. Estimated distribution of GDP growth for four and eight quarters ahead

Frequency

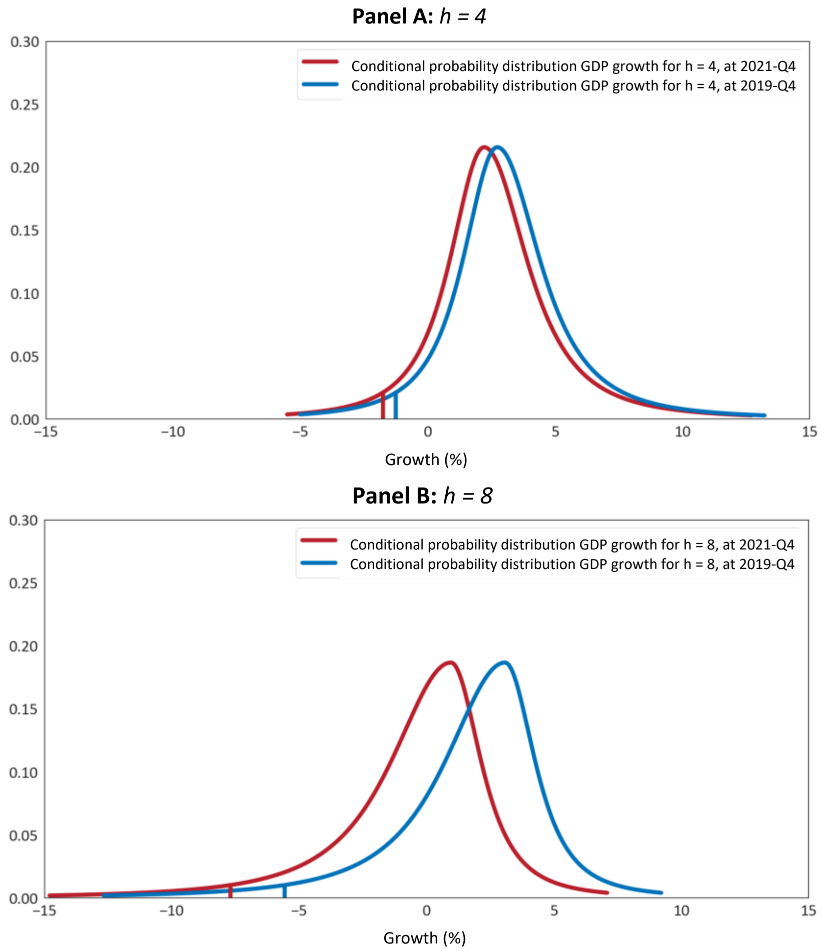


Note. The figure shows the probability distributions for GDP growth for four (h=4) and eight (h=8) quarters ahead from the latest outcome of the Financial Conditions Index (Q4 2021). The probability distributions are estimated using quantile projections. The vertical lines mark GaR (the fifth percentile in the distributions).

Source: Authors' own calculations.

Chart 13. Estimated distribution of GDP growth for four and eight quarters ahead

Frequency



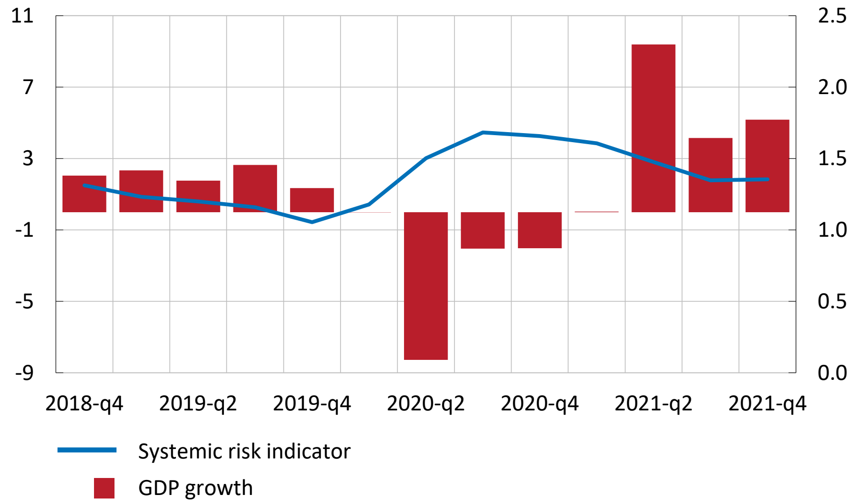
Note. The figure shows the probability distributions for GDP growth for four (h=4) and eight (h=8) quarters ahead given data up to Q4 2021 and to Q4 2019. The probability distributions are estimated using quantile projections. GaR is estimated for each point in time and is marked by vertical lines in the distributions. FCI is used as an explanatory variable.

Source: Authors' own calculations.

APPENDIX – Additional figures

Chart 14. GDP growth and systemic risk indicator over the last four years

Net figures, deviation from mean



Note. GDP growth is expressed as annual growth on a quarterly basis (left axis). The systemic risk indicator is expressed as standard deviations from the mean (right axis). For more information on the indicator, see D. Krygier and P. van Santen (2020), "*A new indicator of risks and vulnerabilities in the Swedish financial system*", Staff Memo, Sveriges Riksbank. See also Chart 1 for a longer time series.

Source: Statistics Sweden and the Riksbank.

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