FI Analysis No. 43

d-SRI: A systemic risk indicator for Sweden

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Summary

Cyclical systemic risks typically build up when lending conditions are loose and asset prices increase. Financial crises have often arisen following such periods. However, high credit growth and rising asset prices can also be an indication that the future prospects of the economy are good. It is therefore difficult to quantify the build-up of cyclical systemic risks. One commonly used indicator is the credit-to-GDP gap. However, the credit-to-GDP gap can be misleading during long periods of high lending.

In an attempt to estimate when cyclical systemic risks increase, the European Central Bank (ECB) has developed the domestic systemic risk indicator (d-SRI). This indicator is comprised of several components, each of which reflect different dimensions of cyclical systemic risk. d-SRI is intended to give an early warning signal before crises caused by domestic imbalances arise. This enables decision makers to build up resilience before a crisis emerges. This FI analysis serves to adapt d-SRI to Swedish conditions.

The adapted d-SRI we have developed indicates build-up of risks during the years leading up to the crisis in the 1990s, the 2000 dot-com crash, and the 2008 financial crisis. This is fully in line with how d-SRI is intended to function. As the Riksbank started raising the policy rate to combat inflation in 2022, we have simultaneously witnessed a tightening of credit lending and falling asset prices. As a result, the d-SRI is currently showing that financial conditions are tight.

d-SRI can contribute by providing a quantitative assessment of the overall build-up of risks. This facilitates FI's work as a macroprudential authority. However, d-SRI is not an indicator for studying specific risks at close range. Depending on the component that is driving the development, it instead gives us an indication of where in the economy imbalances are increasing and requires closer analysis.

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* The author would like to give special thanks to Michael Andersson, Irina Andone Rosén, Johan Berg, Tobias Cronbäck, Magnus Karlsson, Nikita Koptyug, Karin Lindell and Stefan Palmqvist.

The FI Analysis series has been presented at an internal seminar at FI. The report has been approved for publication by an Editors' Board.

Important to monitor cyclical systemic risks

Systemic risk refers to the risk of there being such severe problems in the financial system that the real economy is negatively impacted. When systemic risks increase, the economy is more vulnerable to shocks. In this FI analysis, we attempt to quantify the build-up of cyclical systemic risks using the d-SRI systemic risk indicator developed by ECB (see Lang, et. al. (2019)). We have made adaptations to better reflect Swedish conditions and FI's access to data.

Cyclical systemic risks are typically built up when an optimistic economic outlook, low pricing of risk, rising asset prices, and generous credit assessments converge in a manner that leads to excessive credit growth. Economic or financial crises have often arisen following such periods. But high credit growth does not mean that systemic risks are increasing. High lending can also reflect that the outlook for the economy is genuinely positive or that firms and households have good investment opportunities.

It is therefore difficult to quantify cyclical systemic risks. The credit-to-GDP gap is an indicator that is often used.[1] The credit-to-GDP gap measures how the private non-financial sector's loans in relation to GDP deviate from their historical trends. The credit-to-GDP gap was developed as a method for measuring the cyclical dimension of systemic risks.[2] However, there are some inherent weaknesses to the credit-to-GDP gap that make it less suitable as an early warning indicator.[3] The main reason is that the credit-to-GDP gap can be misleading following a long period where lending increases rapidly. During such periods, the estimated trend closes in on the actual lending over time, meaning the estimated trend also starts to grow unsustainably. This causes the gap to close and the measurement to underestimate the build-up of systemic risks.

Due to the credit-to-GDP gap’s weaknesses, FI puts less emphasis on the gap when determining how systemic risks build up. Due to the credit-to-GDP gap's shortcomings, ECB has developed the d-SRI indicator to better reflect when cyclical systemic risks build up. d-SRI is a more comprehensive risk indicator that

[1] What we mean by credit-to-GDP gap is the one-sided HP filtered gap, see European Systemic Risk Board (ESRB) (2014).
[2] See Aldasoro, Borio and Drehmann (2018), Borio and Drehmann (2009), Borio and Lowe (2002) or Detken et al. (2014).
[3] Alternative estimations of the credit-to-GDP gap avoids some of the shortcomings of the one-sided HP filtered gap in ESRB (2014), see Giordani et al. (2011). However, because the one-sided HP filtered gap is used as the basis for policy and literature, we use it for our comparison.

identifies cyclical systemic risks originating from imbalances on the housing market, the pricing of risk, within the credit provision and external imbalances. It is created to identify vulnerabilities that are beginning to build up and is meant to function as a good early warning indicator. It is intended to guide decision makers in taking timely measures to ensure a build-up of resilience before a crisis occurs.

To identify needs for and calibrate macroprudential measures, it is important that macroprudential authorities such as FI can identify when credit growth is not only high, but exaggerated, and systemic risks increase. d-SRI can contribute to this by providing a quantitative assessment of the overall risk build-up in the Swedish economy. However, d-SRI is not an indicator for studying specific risks at close range. Depending on which component is driving the development of d-SRI, we do get an indication of where in the economy imbalances are building up and requires deeper analysis.

d-SRI is made up of six components

According to Lang et al. (2019), a crisis is defined as threatening the financial system and originating from domestic imbalances, or a combination of domestic imbalances and foreign factors.[4] For Sweden, only the 1990s crisis is defined as being a crisis. According to the ESRB crisis database, the 2000 dot-com crash and the 2008 financial crisis are not considered to be crises caused by domestic imbalances in Sweden.

Lang et al. (2019) started from pre-determined risk categories from ESRB (2014) that have been good at predicting financial crises. The risk categories are presented in the section below. In each risk category, Lang et al. (2019) evaluate the early warning performance of several variables. The early warning performance is measured as a combination of the variable’s ability to predict crises in ESRB's crisis database both in- and out of sample. See Appendix A for a more detailed explanation of the method.

Risk categories

d-SRI is composed of six components (see Table 1). Lang et al. (2019) use data from the ECB database for the components. We use the same data for all countries except Sweden. For Sweden, we instead use the equivalent data from Statistics

[4] Lang et al. (2019) are the creators of the model on which the d-SRI calculation is based.

Sweden (SCB). This does not impact the results but has the benefit of us having better access to Statistics Sweden's data.

Credit development*:* High lending in the economy can reflect that the outlook for the economy is good or that firms and households have good investment opportunities. However, rapidly growing lending has historically been a robust indication of growing cyclical systemic risks. Cyclical systemic risks increase when lending conditions are loose while there is strong optimism about households' and non-financial firms' current or expected cash flows, asset values, or the degree of activity in the real economy. Lang et al. (2019) includes two variables for the credit development category. The two-year rate of change of the bank credit[5] in relation to GDP ratio and the two-year rate of change of total credit[6] in real terms are the variables that capture this dimension best.

Mispricing of risk: The mispricing of risk category captures how financial risk-taking contributes to cyclical systemic risk. During periods of high optimism and confidence about the future, various types of risks can be underestimated and thereby be mispriced, leading to rapidly increasing asset prices. High risk-taking makes the economy vulnerable to shocks that change the future prospects of the economy and can lead to severe corrections of asset prices. This can create major losses and lead to financial turbulence. The three-year change of equity prices in real terms is the variable that captures this dimension best.

External imbalances: The external imbalances category captures how changes to capital flows in and out of a country impact cyclical systemic risk. The current account is one measure of external imbalances. The current account shows the difference between a country's income and expenses. If a country consumes more than it produces, it results in a negative current account balance. This means that the country as a whole borrows from abroad. A negative current account balance over time does not necessarily indicate a problem. But consistently showing a significant current account deficit as a proportion of GDP leads to high foreign debt and has often shown to lead to crises in countries with a fixed exchange rate regime. Current account-to-GDP is the variable that captures this dimension best.

The housing market: Housing and property prices tend to co-move with lending as purchases of such assets are often financed through loans. Cyclical systemic risks can build up when asset prices are high and lending conditions are loose, making housing and property prices good measures of risk build-up. Banks', households' and certain non-financial firms' balance sheets are connected to a

[5] Bank credit refers to outstanding loans to households and non-financial firms and holdings of securities from households and non-financial firms that monetary financial institutions have on their balance sheets.
[6] Total credit refers to households' and non-financial firms' total loans and outstanding securities. That is, not only debt to monetary financial institutions.

great degree to the value of housing and property. For this reason, they are vulnerable to substantial price corrections of these asset types. Banks also use mortgages as collateral in their financing. Many historical financial crises have originated in overheated housing and property markets that have collapsed. When prices fall, households and firms lose wealth and the credit risk increases for lenders. The three-year change in the residential real estate price-to-income ratio is the variable that captures this dimension best.

Debt burden: A high debt burden makes households and firms vulnerable to shocks as they have less room to compensate for a large loss of income or cost increases. With high borrowing costs, even minor losses of income or cost increases can significantly reduce households' and firms' ability to consume and invest. This can lead to households and firms defaulting on their debts (Drehmann and Jueselius, 2012). The Bank for International Settlements (BIS) has developed a measure of the debt-service-ratio for the private non-financial sector. It is the two-year change of BIS's measure of the debt-service-ratio that Lang et al. (2019) use.

BIS's measure of the debt-service-ratio should reflect the private non-financial sector's debt service costs for their loans in relation to their income. Interest and amortisation payments are debt service costs. But BIS does not have actual amortisation payment data, which entails certain shortcoming with their calculation. In part, they assume a constant amortisation rate and a very short repayment period and in part, the time series does not stretch back far enough. For this reason, we have constructed a variable that co-varies well with BIS's measure. The variable we have created is the two-year change in households' and non-financial firms' total loans as a share of GDP. Though this variable differs from BIS's measure, we believe it is a good simplification that reflects the private non-financial sector's debt burden well.

Table 1. d-SRI consists of six variables that together have the best early warning performance

Risk category	Variable
Credit development	Two-year change of bank credit-to-GDP.
Credit development	Two-year real total credit growth.
Mispricing of risk	Three-year real equity price growth.
External imbalances	Current account-to-GDP ratio.
The housing market	Three-year change of residential real estate price-to-income ratio.
Debt burden	Two-year change of debt-service-ratio for the private non-financial sector.

Source: ECB

Result for the adjusted d-SRI

Introductory explanations of d-SRI

In this section, we discuss the components that have driven the result of d-SRI. We will also provide a sensitivity analysis of various d-SRI variants. Both variables in the credit development risk category and the variable for debt burden reflect lending in the economy. Housing prices also co-move with lending as housing purchases are often financed through loans. This entails that four of the six variables reflect lending in the economy and that d-SRI is strongly driven by the credit development. This is natural as most of the crises in the ESRB crisis database are credit-driven. The drawback is that d-SRI probably misses other aspects of cyclical systemic risk build-up. But it is impossible to capture all dimensions of cyclical systemic risk and d-SRI is not intended to be an exhaustive measure of all the risks in an economy. d-SRI is intended to give an overall picture of risk build-up based on historical correlations between risk build-up and crises.

Lang et al. (2019) estimates d-SRI using data between Q1 1980 and Q2 2017 for all EMU countries, Sweden, Denmark and the UK. As a starting point, we evaluated how robust the results of Lang et al. (2019) are when updating data from Q2 2017 to Q2 2022.[7] We compare different variants of d-SRI to enable various considerations when assessing the model. The results of the optimal weights and the early warning performance are unchanged in all d-SRI variants. The early warning performance of the four variants is displayed in Table 2. Though we have not focussed on the optimal weights of the different variants in this analysis, we nonetheless display them in Table 4 of Appendix B.

We evaluate the variants by comparing their early warning performance. We follow the same method as in Lang et al. (2019) and define early warning performance as the weighted total of the indicator's ability to forecast the financial crisis variable in and out of sample. The AUROC measure (Area Under Receiver Operating Characteristics) measures in sample performance. The measure relative usefulness measures out of sample performance.[8] According to the method, we give AUROC two-thirds weight and relative usefulness one-third. Early warning performance is rated on a scale of zero to one. The higher the rating, the better the early warning performance (see Table 2).

We have chosen to compare four d-SRI variants for Sweden. In part, we use the variant that Lang et al. (2019) refers to as the d-SRI benchmark. However, we also test a country-specific variant for Sweden, one without a current account component, and one that starts from Q1 1995 (instead of Q1 1980). The benchmark

[7] Our analysis ends at Q2 2022 due to data availability limitations in the ECB database.
[8] For a more in-depth explanation of AUROC and relative usefulness, see Appendix A.

variant uses data from every country when components are normalised. The country-specific variant for Sweden only uses Swedish data for normalisation.[9] The advantage of the benchmark variant is that it sets the Swedish components' development in relation to the median and standard deviation for all countries in the dataset. The disadvantage of the benchmark variant is that the development of foreign components has just as much of an impact on the median and standard deviation as Sweden's components. After normalisation, the early warning performance of the variables is evaluated. Because the early warning performance is estimated on the entire panel dataset, this means that the country-specific variant uses all the countries' data in the estimation. Since we have numerous crises to assess the model against, the results are more robust than if we were only to estimate the model against Swedish crises.

The structure of the Swedish economy has changed considerably since 1980. For example, Sweden has implemented a variable exchange rate regime, an inflation target and a fiscal policy framework since the 1990s crisis. To evaluate how structural changes can impact d-SRI, we have therefore chosen to create a variant without the current account component. According to macroeconomic theory, a variable exchange rate works as a cushion when there are large inflows and outflows of capital. Because Sweden abandoned its fixed exchange rate in 1992, we want to assess how the d-SRI for Sweden develops if we exclude the current account component. We have also chosen to evaluate a variant that only takes data starting in Q1 1995 into consideration. We chose the first quarter of 1995 because that is when we believe the major structural changes to the Swedish economy had been put in place.

The early warning performance ranges from zero to one where one is perfect performance. The country-specific d-SRI has the best early warning performance (see Table 2). We will evaluate the driving forces of this variant in more detail later in the chapter. The other three variants are a sensitivity analysis of the results. In the remainder of this FI Analysis, we will refer to the country-specific d-SRI as d-SRI-SE.

[9] Normalisation means that the variable is adjusted for its mean and divided by its standard deviation. Each variable then has a mean value of 0 and a standard deviation of 1. Another method is the one Lang et al. (2019) and we use, which adjusts the variable with its median and divides by the standard deviation.

Table 2. The country-specific variant performs best as an early warning indicator

Enter unit

d-SRI variants	d-SRI benchmark	d-SRI country-specific	d-SRI excl. current account	d-SRI 1995
Early warning performance	0.747	0.775	0.749	0.678

Source: FI.

Interpreting d-SRI

It is difficult to assess cyclical systemic risks. The strength of d-SRI is that it clearly shows phases of risk build-up sufficiently early before a crisis occurs. The weakness of d-SRI is that it is unclear how the periods during and after a crisis are to be interpreted. When the d-SRI drops, it can be interpreted to mean that the level of cyclical systemic risks is decreasing and that vulnerabilities in the economy are reducing. But it is not that simple. Most of the components in the d-SRI are growth rates. According to Lang et al. (2019), growth rates tend to peak earlier than level variables do before a crisis. This means that when the d-SRI rapidly drops, the vulnerabilities in the economy do not necessarily decrease. The growth rates go down, but not necessarily the imbalance levels. When the d-SRI drops quickly, it should instead be interpreted as being a turning point in the cycle. The turning point means that financial conditions in the economy are significantly tighter than in the risk build-up phase.

A sudden change in financial conditions can, in itself, increase the risk of a crisis. This interpretation is currently very relevant considering the increase of inflation and the raising of policy rates by central banks. It has resulted in tighter lending conditions and falling asset prices. It has led to a turning point in the cycle because we have gone from very low interest rates to higher interest rates. We interpret this to mean that a potential risk build-up phase is over. But the clear drop of the d-SRI means that there is a substantial risk that vulnerabilities in the economy can reveal themselves. FI has warned of precisely this since the Riksbank began to raise the policy rate in 2022 (FI Stability Report 2022:2).

d-SRI-SE provides best early warning

d-SRI-SE has indicated historical periods of risk build-up

d-SRI-SE has the best early warning performance. Therefore, we will continue to use it to evaluate the various components. d-SRI as an indicator should peak two to three years before a crisis is realised. d-SRI-SE peaked in Q4 1989 (see Diagram

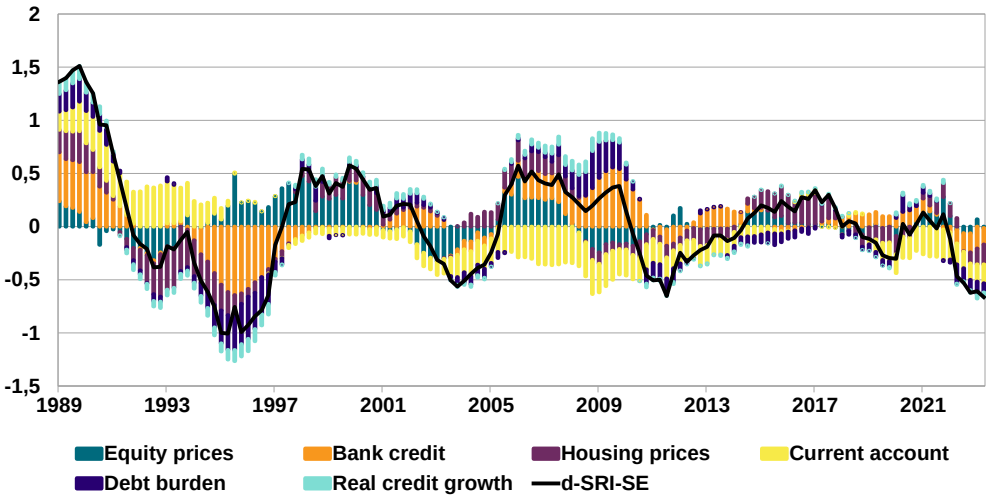
1), which is in line with how the indicator is intended to work. The risk build-up prior to the 1990s crisis was primarily driven by rapid credit growth, rising housing prices and a large current account deficit. Once the crisis was a fact, we can see how d-SRI-SE rapidly decreased, driven by all components contributing to tighter financial conditions. The 1990s crisis is the only domestic crisis for Sweden in the ESRB crisis database. Therefore, it is natural that we see the greatest risk build-up before the 1990s crisis and a rapid decrease in d-SRI-SE during the crisis as financial conditions were rapidly tightened.

There are other periods that are not defined as being a crisis but for which the indicator shows risk build-up followed by considerably tighter financial conditions. The first is the dot-com crash around the year 2000. This period was characterised by strong optimism of how the internet would greatly improve productivity in the economy. As a result, equity prices rose significantly. This is clearly reflected in the d-SRI-SE. A new period of risk build-up started in Q1 1996 and was primarily driven by the equity price component. The risk build-up started from a low level and did not reach the same levels as prior to the 1990s crisis. However, the rapid rise in d-SRI-SE between Q1 1996 and Q4 1999 gives a good indication that vulnerabilities were building up in certain parts of the economy. After the dot-com bubble burst, we see a prolonged period of tighter financial conditions.

Before the 2008 financial crisis, the risk build-up was broader as both the credit development and asset prices contributed to it. This is more in line with how FI views cyclical systemic risks as being an interaction between expansive credit growth and rising asset prices. But Sweden’s large current account surplus during these years contributed to dampen the level of d-SRI-SE. Just as before the dot-com crash, d-SRI-SE started at a low level and never reached the high levels of the 1980s. However, the rapid build-up of cyclical systemic risks prior to the 2008 financial crisis gave a good indication of imbalances in the Swedish economy as well. During and after the 2008 financial crisis we see a prolonged period of tighter financial conditions.

1. d-SRI-SE captures historical periods of risk build-up

Normalised value



Source: FI, SCB and ECB

Note: Normalised value is when you subtract the median from the observation and divide this by the standard deviation, see Footnote 8.

d-SRI-SE indicates tighter financial conditions as interest rates have increased

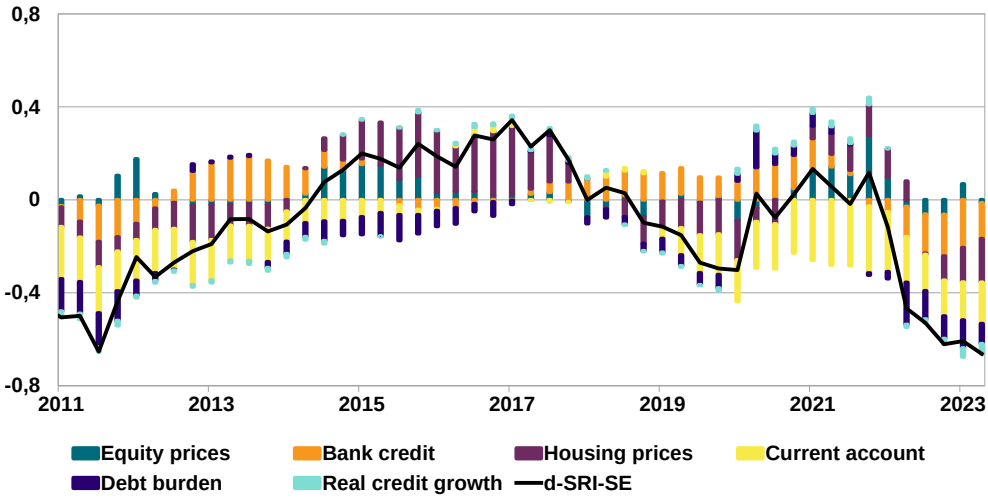
After the 2008 financial crisis, central banks in most developed countries pursued a very expansionary monetary policy. Low interest rates stimulate lending and increase financial risk-taking. A very expansionary monetary policy can eventually lead to imbalances building up. The low and stable level of d-SRI-SE between 2011 and 2022 does not clearly indicate that cyclical systemic risks were building up during these years. But the increase between 2013 and 2018 nonetheless indicates that minor imbalances were building up (see Diagram 2). Between 2013 and 2015, it was bank credit that indicated a certain risk build-up and between 2015 and 2018, it was primarily housing prices that contributed to a rise in the d-SRI-SE. Even though the trend is that d-SRI-SE increased during these years, it does not clearly indicate that cyclical systemic risks were being built up. A possible explanation is the macroprudential measures taken in Sweden during this period. Since the 2008 financial crisis, most developed countries implemented measures to reduce risk build-up in the economy. However, d-SRI is a measure of overall risk build-up, not a measure for evaluating how effective macroprudential measures have been. Closer analyses of different areas of the economy are more effective at evaluating the effect of macroprudential measures.

At the start of 2022, inflation began to rise and the Riksbank raised the policy rate. This resulted in a rapid decline in d-SRI-SE. In 2022 and 2023, tighter lending conditions, falling asset prices and a current account surplus contributed to tighter financial conditions in Sweden. This differs from earlier periods as d-SRI-SE did

not show a clear phase of risk build-up before the financial conditions were tightened. This is entirely in line with how d-SRI is intended to work. The high inflation is a consequence of many factors. In the beginning, it was a foreign impulse in the form of pandemic lockdowns and the war in Ukraine. During much of 2023, prices for services have driven Swedish inflation. Though this has real economic consequences for Sweden, it is not an economic decline caused by the build-up and materialisation of cyclical systemic risks in Sweden. It is therefore reasonable that we do not see a clear period of risk build-up but we do see considerably tighter financial conditions in Sweden at the moment.

2. d-SRI-SE between 2011 and 2023

Normalised value



Source: FI, SCB and ECB

Note: Normalised value is when you subtract the median from the observation and divide this by the standard deviation, see Footnote 8.

Sensitivity analysis of d-SRI variants

We evaluate the early warning performance of four d-SRI variants. It is the same components that drive the result of d-SRI-SE as the three other variants. What sets the variants apart is the level at certain points in time (see Diagram 3). This is because the different variants calculate different optimal weights for the components. [10] The clearest difference in level is between d-SRI excl. current account and the other variants. This is due to great weight being put on bank credit when the current account is excluded. This creates clear level differences when the bank credit component either increases or decreases strongly. All d-SRI variants show risk build-up before followed by tighter financial conditions during and after the 1990s crisis, the 2000 dot-com crash and the 2008 financial crisis. However, d-

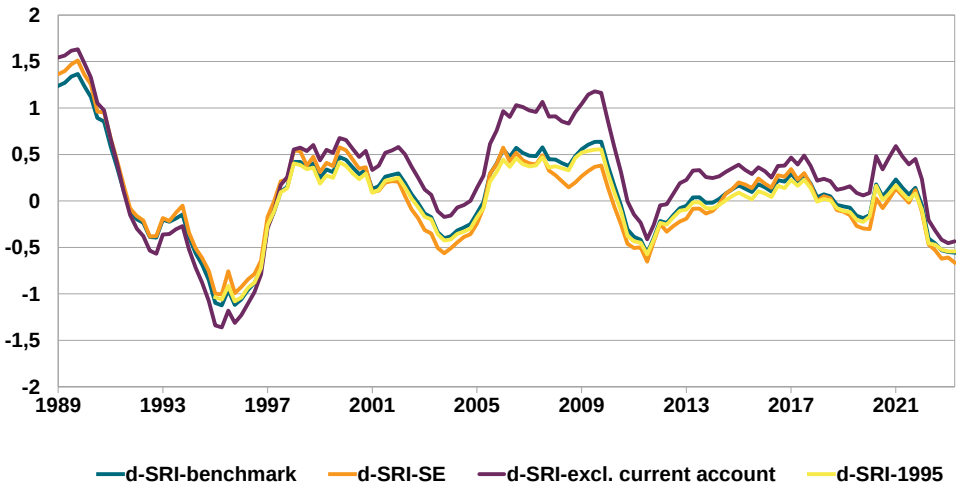
[10] See Table 4 in Appendix B for the differences in optimal weights between the variants.

SRI-SE is the only one to reach a local peak before both the 2000 dot-com crash and the 2008 financial crisis. Though neither the 2000 dot-com crash nor the 2008 financial crisis are defined as crises in this analysis, they are nonetheless episodes that d-SRI should warn for in advance.

We make two adjustments to the calculation of d-SRI in order to take the structural changes in the Swedish economy into account. These variants are called d-SRI 1995 and d-SRI excl. current account. Both these variants, however, perform worse than d-SRI-SE in providing an early warning signal. This is to say that excluding the large movements during the 1980s and beginning of the 1990s does not significantly change the level of the indicator and it makes the indicator perform worse. The variant that excludes the current account has the second-best early warning performance. This means that the indicator's early warning performance does not improve when we take the structural transition from a fixed exchange rate to a variable one into account. The fact that the current account component is included in the variant with the best early warning performance shows that capital flows are important for gauging the build-up of cyclical systemic risks despite having implemented a variable exchange rate.

3. The different variants move in a similar way, but d-SRI-SE has the best early warning performance

Normalised value



Source: FI, SCB and ECB

Note: Normalised value is when you subtract the median from the observation and divide this by the standard deviation, see Footnote 8.

d-SRI is part of the overall assessment

A potential problem with d-SRI is in normalising the components. In the very long run, it can be expected that the growth rates of variables such as bank credit in

relation to GDP should be zero per cent on average. It would not be sustainable in the very long run if they were to grow indefinitely. But in our data for Sweden, all components have a median over zero. In other words, our data is not in agreement with the theoretical assumption that our variables cannot grow indefinitely. From a theoretical point of view, this results in an underestimation of the calculation of risk build-up because all normalised components would show a higher value if their median was zero instead of a positive value. This is not a problem for d-SRI specifically but rather for most of the models calculated using data from the most recent decades.

The problem of calculating the level of risks does not only pertain to d-SRI. It means that macroprudential measures are decided upon based on many different indicators and expert judgments. For this reason, d-SRI is not an indicator for fine-tuning macroprudential measures. But it does give an estimation of cyclical systemic risk build-up and is part of the overall assessment of Swedish financial stability. Because d-SRI attempts to estimate the overall build-up of cyclical systemic risks, it is not an indicator for studying individual risks more closely. But depending on which component is driving the development, we get an indication of where imbalances are building up in the economy. This gives us an indication of where in the financial system we need to take a closer look.

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Appendix A

Summary of the d-SRI method

Here, we give a qualitative description of the method Lang et al. (2019) use to create the d-SRI.

ESRB has compiled a database which they use to define financial crisis periods in European countries (ESRB 2017). The database goes back to 1970 and includes all EMU countries, Sweden, Denmark and the UK. To identify crisis periods, ESRB uses quantitative measures of financial stress and expert judgments from national macroprudential authorities. What is special about the database is that it differentiates crisis periods that arise from domestic factors, foreign factors, or a combination of these. The database also defines which crisis periods were a threat to the entire financial system and which were not. This information is key because it helps limit the analysis to the crises that were a threat to the system and depended either solely on domestic factors or on a combination of domestic and foreign factors.

To find the variables that work best in providing an early warning, Lang et al. (2019) identifies various risk categories that, according to the literature, have performed well in forecasting financial crises. The risk categories are credit development, mispricing of risk, the housing market, debt burden and external imbalances. Within each risk category, they identify several variables that are thought to perform well in the forecasting exercise. For instance, in the credit development risk category, they study on the one hand bank lending in relation to GDP and on the other, more specific variables such as the rate of change of non-financial firms' loans over time. For all variables they also test various transformations such as different growth rates to understand which transformation performs best as an early warning indicator.

Lang et al. (2019) define early warning performance as the weighted average of the variable's ability to forecast crises in and out of sample. The measure for in sample forecast performance has a weight of two-thirds and the measure for out of sample performance has a weight of one-third. In sample forecast performance is measured using "Area Under Receiver Operating Characteristics" (AUROC). To put it simply, we can split the measure into two parts. ROC is a curve that shows the relation between the variable's ability to correctly indicate a crisis (true positive) and incorrectly indicate a crisis (false positive) for different values of the indicator threshold. AUROC is the area under the ROC curve and provides a measure of the forecast performance of the variable. The measure is between zero and one where a value of one indicates perfect forecast performance. A value of 0.5 means that the

variable indicates a crisis entirely at random and therefore has no value as an indicator. They measure the out of sample forecast performance using relative usefulness. This measure evaluates the number of missed crises (false negatives) and the number of false alarms (false positives). This means that if the variable gives incorrect indications too regularly, it is better to disregard the variable than to use it. The relative usefulness measure is also on a scale of zero to one with one being perfect forecast performance.

To test which variables perform best as an early warning signal, Lang et al. (2019) create a vulnerability indicator that has a value of one during the crisis build-up phase and zero during the crisis. They evaluate each variable's early warning performance by testing various build-up phase lengths and then comparing the variable's ability to make forecasts in and out of sample. Through this, they rank each variable based on early warning performance. The result was that a number of credit and asset price variables performed better as an early warning indicator than the credit-to-GDP gap.

Using the pre-determined risk categories, they select the variable with the best early warning performance from each risk category. But because some variables are growth rates and others are ratios, it can be difficult to compare them. Therefore, they normalise every variable by subtracting the median and dividing by the standard deviation. Normalising a variable makes it easier to see how an observation relates to its historical distribution.

The d-SRI systemic risk indicator is a combination of the normalised variables. To obtain the d-SRI, they estimate optimal weights through a linear regression of the vulnerability indicator in which all six variables are explanatory variables. They determine the optimal weights by adding the coefficients and calculating each coefficient's proportion. Table 3 below summarises which risk categories and variables make up d-SRI and in which direction the variables move to indicate cyclical systemic risk build-up.

Table 3. d-SRI is a combination of several components

Enter unit

Risk category	Variable	Direction for increased risk
Mispricing of risk	Three-year real equity price growth	+
External imbalances	Current account-to-GDP ratio	-
The housing market	Three-year change of residential real estate price-to-income ratio	+
Debt burden	Two-year change of debt-service-ratio for the private non-financial sector	+
Credit development	Two-year change of bank credit-to-GDP	+
Credit development	Two-year real total credit growth	+

Source: ECB
Note: Enter note

Because the credit development risk category is important as an early warning indicator, the authors wish to capture the entire dimension of this risk category. Lang et al. (2019) therefore include both bank credit and total credit to capture any possible structural changes to the financial sector such as whether lending is increasing outside the banking sector. It is worth noting that we mean both bank and market financing when we refer to credit.

Appendix B

Optimal weights differ between the variants

d-SRI benchmark is the standard variant of the indicator in which we both normalise the components and calculate the model using data from all countries for the entire time period. d-SRI country-specific calculates the model using all countries' data but normalises the components individually for each country. d-SRI excl. current account uses all countries' data for calculating and normalising but excludes the current account component. d-SRI 1995 calculates and normalises using all countries' data but starting from Q1 1995. Because the methods differ somewhat for the four variants, the optimal weights become different. Table 4 presents the differences. The variant excluding the current account disperses the weights over the remaining five components. Just as in Lang et al. (2019), the bank credit component generally increases most when we exclude another component.

Table 4. The optimal weights differ between the variants

Weights in per cent	d-SRI benchmark	d-SRI country-specific	d-SRI excl. current account	d-SRI 1995
Equity prices	17	21	17	16
Bank credit	36	22	52	35
Housing prices	17	17	21	15
Current account	20	22	0	24
Debt burden	5	13	5	5
Real credit growth	5	5	5	5

Source: FI.
Note: Enter note