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Pierre Berthonnaud, Enrico Cesati, Maria Ludovica Drudi, Kirsten Jager, Heinrich Kick, Marcello Lanciani, Ludwig Schneider, Claudia Schwarz, Vasileios Siakoulis, Robert Vroege

Asset encumbrance in euro area banks: analysing trends, drivers and prediction properties for individual bank crises

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Abstract

Asset encumbrance is a central concept in the context of banks' liquidity crises, as it is associated with their capacity to obtain secured funding. This occasional paper summarises the work carried out by the task force on asset encumbrance, bringing together analyses by the ECB and those national competent authorities working on the topic. First, we describe how asset encumbrance has evolved in euro area banks, focusing on country and business model aggregates. Second, we conduct an econometric analysis of the driving factors of banks' asset encumbrance, highlighting the relevance of credit risk, the availability of high quality collateral suitable for encumbrance, capital and sovereign funding conditions. Third, we turn our focus to the asset encumbrance dynamics of banks that have experienced a crisis. The outcome of this event study analysis indicates that asset encumbrance increases in the lead-up to a crisis, partly to offset early deposit outflows. Building on these findings, we show that asset encumbrance indicators carry predictive information for bank-specific crises as part of a multivariate early warning model.

Keywords: asset encumbrance, liquidity, bank funding, collateral, bank crisis, early warning model, panel econometrics

JEL codes: G21, G01, G28, C23, C49

Executive summary

After the global financial crisis of 2008, the growing risk aversion that pervaded the banking sector had a strong impact on the funding structure of financial institutions. Investors reacted to increased counterparty credit risk either by seeking higher risk premia or by demanding collateral, thereby generating pressure on banks to shift from unsecured to secured funding. The capacity to obtain secured funding, from which asset encumbrance arises, is thus a key element for banks to ensure stable funding in crisis situations.

Asset encumbrance arises from the issuance of secured funding instruments, such as covered bonds, repurchase agreements (repos), over-the-counter (OTC) derivatives and central bank funding. Secured funding requires the collateralisation of bank assets, which restricts the bank's ability to transfer or realise these assets. Assets pledged as collateral, which are not available to meet the claims of unsecured creditors in the event of a default, are said to be encumbered.

In recent years, asset encumbrance has been a growing topic for discussion among regulators, policymakers and supervisors. The debate has focused on identifying and addressing excessive asset encumbrance, both on a bank-by-bank and at a system-wide level, and on examining its potential impact on the financial system. Bank failures related to liquidity shortages underline the need for a better understanding of the concept of asset encumbrance: high encumbrance levels could lead to the failure even of banks with a sound capital base.

This occasional paper contributes to the existing literature on asset encumbrance in three ways.

First, using supervisory reporting data from euro area banks, it provides insights into asset encumbrance dynamics across countries and business models. Results show that the aggregate asset encumbrance ratio (AE ratio) among euro area banks has remained relatively stable since 2015. However, there is considerable heterogeneity across both countries and business models.

Second, it empirically investigates the drivers of asset encumbrance. Our findings show that: (i) banks with higher asset-side risk, as measured through non-performing loans (NPLs), tend to rely more on asset encumbrance; (ii) an increased availability of central bank-eligible collateral increases the appetite for asset encumbrance; (iii) banks' access to unsecured funding is affected by the sovereign-bank nexus, with increases in domestic government yields being reflected in higher AE ratios; and (iv) a convex relationship between capitalisation and asset encumbrance is found to be significant in some – but not all – econometric specifications.

Third, the paper identifies increases in asset encumbrance that have preceded bank crises. Building on this pattern, we establish that identifying changes in asset encumbrance increases the accuracy of a multivariate early warning model for predicting bank crises.

1 Introduction

In recent years, asset encumbrance has been a growing topic for discussion among regulators, policymakers and supervisors. The debate has focused on identifying and addressing excessive asset encumbrance, both on a bank-by-bank and at a system-wide level, and on examining its potential impact on the financial system. Bank failures related to liquidity shortages underline the need for a better understanding of the concept of asset encumbrance: high encumbrance levels could lead to the failure even of banks with a sound capital base.

In 2011 Dexia Bank had to be rescued by the French and Belgian governments despite having sufficient capital at the time, with excessive levels of asset encumbrance being cited as one of the key reasons for the bailout.[1] A more recent case in Europe is Banco Popular, which was acquired by Banco Santander in 2017 after significant liquidity troubles. Like Dexia Bank, Banco Popular had a satisfactory capital ratio and passed the European Banking Authority (EBA) stress test. However, an excessive level of asset encumbrance undermined its liquidity conditions (Banal-Estanol et al., 2019). Asset encumbrance and banks' ability to mobilise additional collateral was an integral part of the ECB's 2019 liquidity stress test,[2] capturing the capacity of collateral buffers to help banks withstand a hypothetical deposit run and funding freeze.

Asset encumbrance arises from the issuance of secured funding instruments, such as covered bonds, repos, OTC derivatives and central bank funding. Secured funding requires the collateralisation of bank assets, which restricts the bank's ability to transfer or realise those assets. The alternative to secured funding is unsecured funding, which is backed not by collateral but by the creditworthiness of the issuer. Assets pledged as collateral, which are not available to meet the claims of unsecured creditors in the event of a default, are said to be encumbered.

Financial institutions face a trade-off when choosing between secured and unsecured funding. As secured funding is backed by collateral, and thereby safer for the investor, funding costs are generally lower for this type of instrument. This can incentivise banks to increase their proportion of secured funding, which in turn leads to higher AE ratios. However, increasing the proportion of secured funding means that fewer – and typically riskier – assets will remain available to meet the claims of unsecured creditors in the event of a default. This structural subordination, which in effect shifts the risk from secured to unsecured investors, arises for two main reasons. First, the value of collateral is often higher than the nominal value of the funding obtained; this is referred to as overcollateralisation. Second, collateral is usually composed of high quality assets, with banks being required to replace assets that no longer meet the collateral requirements. Thus, a higher level of asset encumbrance implies not only a decrease in the assets on which unsecured creditors can exercise their claims, but also an increase in their average riskiness.

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1 See for instance "Bank collateral drying up in rush for security", Financial Times,19 October 2011.

2 See also the associated press release and published results.

This effect of structural subordination increases the costs of unsecured funding and, in the worst cases, could result in runs on unsecured debt, thereby making the issuer more sensitive to shocks (Juks 2012; Bank of England, 2012; Houben and Slingenberg, 2013; CGFS, 2013; Matta and Perotti, 2015). A balance between secured and unsecured funding – obtained by assessing the costs and benefits associated with asset encumbrance – is crucial for financial institutions. This trade-off between cheap funding and fragility is the basis of the theoretical model developed by Ahnert et al. (2019). The authors show that asset encumbrance can lead to illiquidity of solvent banks. In general, because of their structural subordination, unsecured lenders have a greater incentive than secured creditors to monitor the creditworthiness of the borrowing institution, so riskier institutions will more often use collateral (Berger and Udell, 1990, 1995; Boot et al., 1991; Jiménez et al., 2006) as they have limited access to the unsecured market. Focusing on the European interbank repo market, Di Filippo et al. (2020) provide empirical evidence that riskier banks are more reliant on secured funding.

From a microprudential point of view, high levels of encumbrance are an indicator of funding and liquidity risks. The lack of unencumbered assets means that a financial institution could face increased difficulties in obtaining funding, especially in times of financial distress, as too few assets remain available to obtain secured funding, while unsecured funding may become too expensive or unavailable. Discouraged by their structural subordination, unsecured debt holders are more likely to demand higher risk premia or decide not to roll over their funding. Moreover, high quality collateral is required to raise funding from the central bank, which often plays the role of lender of last resort:[3] when liquidity in the financial system dries up, banks rely on central banks for short-term funding. However, financial institutions can only access the central bank's facilities if they can pledge as collateral high quality assets that satisfy the criteria set out by the central bank.

From a macroprudential perspective, a banking system with a high level of encumbrance could be more sensitive to financial shocks and cause procyclical effects (Houben and Slingenberg, 2013; CGFS, 2013; Gai et al., 2013). In the event of financial turmoil resulting in drops in collateral values, increases in haircuts, or the need to substitute non-performing assets, many banks would be forced to simultaneously post additional collateral. When financial institutions can no longer increase the level of encumbrance to sustain their need for funding, they could be forced into fire selling their assets, thereby exacerbating the crisis. Gorton and Metrick (2012) identify drops in collateral values and increased haircuts – at the basis of the "run on repos" – as a triggering event of the global financial crisis.[4] Asset encumbrance can also cause procyclicality as a result of collateral reuse (rehypothecation), which increases interconnectedness and opacity among financial agents (Houben and Slingenberg, 2013; Financial Stability Board (FSB), (2016); Brumm et al., 2018).

Depositor insurance, in the form of a deposit guarantee scheme, might lead banks to increase their AE ratio beyond optimal levels (Juks, 2012; Houben and Slingenberg,

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[3] See Rochet and Vives (2004) on the need for and the role of the lender of last resort.

[4] See also Gorton and Ordoñez (2014).

2013; Hardy, 2013; CGFS, 2013; Helberg and Lindset, 2014; Ahnert et al., 2019). Insured depositors do not ask for higher risk premia to compensate for their structural subordination, as they will be compensated by the insurance fund if the bank fails to meet its obligations. Hence, banks with a large deposit base might find it advantageous to issue secured debt in order to reduce their funding costs. As a result, by increasing their asset encumbrance, financial institutions shift risks to depositors and ultimately to the deposit guarantee scheme.

Policymakers and regulators are therefore tasked with assessing the implications of asset encumbrance for the entire financial system.

This occasional paper focuses on the microprudential perspective and contributes to the existing literature in three ways.

First, using supervisory reporting data from euro area banks, it provides insights into asset encumbrance dynamics across countries and business models. Results show that the aggregate AE ratio among euro area banks has remained relatively stable since 2015. However, there is considerable heterogeneity across both countries and business models.

Second, it empirically investigates the drivers of asset encumbrance. Our findings show that: (i) banks with higher asset-side risk, as measured through NPLs, tend to rely more on asset encumbrance; (ii) a larger availability of central bank-eligible collateral increases the appetite for asset encumbrance; (iii) banks' access to unsecured funding is affected by the sovereign-bank nexus, with increases in domestic government yields being reflected in higher AE ratios; and (iv) a convex relationship between capitalisation and asset encumbrance is found significant in some – but not all – econometric specifications.

Third, the paper identifies increases in asset encumbrance that have preceded bank crises. Building on this pattern, we establish that identifying changes in asset encumbrance increases the accuracy of a multivariate early warning model for predicting bank crises.

The remainder of this paper is structured as follows. Section 2 explains the dataset and the composition of the sample used. Section 3 discusses the aggregate developments with respect to asset encumbrance across banks subject to the single supervisory mechanism (SSM). Section 4 provides an econometric investigation of the drivers of asset encumbrance. Section 5 offers insights into asset encumbrance dynamics during crisis periods and Section 6 tests the usefulness of asset encumbrance as an early warning indicator of crises. Section 7 sets out the conclusions.

2 Data

The financial crisis prompted the Basel Committee on Banking Supervision (BCBS) to strengthen the regulation, supervision and risk management of banks, with the introduction of Basel III. The Basel III framework has been implemented in the European Union by means of Directive 2013/36/EU[5], the Capital Requirements Directive (CRD), and Regulation (EU) No 575/2013[6], the Capital Requirements Regulation (CRR). Article 100 of the CRR requires institutions to report on "repurchase agreements, securities lending and all forms of encumbrance of assets". It also mandates the EBA to incorporate this information in the implementing technical standards (ITS). In this regard, the EBA first implemented asset encumbrance reporting on 31 December 2014.

In accordance with Commission Implementing Regulation (EU) No 2015/79[7], the AE ratio is defined as the sum of total encumbered assets and collateral received and reused,[8] divided by the sum of total assets and total collateral received and available for encumbrance.[9] For the sake of conciseness, we will refer to collateral received and available for encumbrance as "total collateral" or simply "collateral". The AE ratio is one of the dependent variables in the econometric analysis presented in Section 4. It is also tested in the early warning indicator analysis (Section 6) as a crisis prediction factor, together with other asset encumbrance indicators. These include the ratio of unencumbered central bank-eligible assets and collateral to total assets and collateral, which serves as a proxy for the liquidity that can be obtained in times of stress. Counterbalancing capacity, or "the stock of unencumbered assets or other funding sources which are legally and practically available […] to cover potential funding gaps",[10] is also tested.

The data used in this occasional paper were obtained from financial reporting on asset encumbrance. The data have been collected since December 2014 and cover encumbered assets and collateral, sources of encumbrance and contingent

5 Directive 2013/36/EU of the European Parliament and of the Council of 26 June 2013 on access to the activity of credit institutions and the prudential supervision of credit institutions and investment firms, amending Directive 2002/87/EC and repealing Directives 2006/48/EC and 2006/49/EC (OJ L 176, 27.6.2013, p. 338).

6 Regulation (EU) No 575/2013 of the European Parliament and of the Council of 26 June 2013 on prudential requirements for credit institutions and investment firms and amending Regulation (EU) No 648/2012 (OJ L 176, 27.6.2013, p. 1).

7 Commission Implementing Regulation (EU) 2015/79 of 18 December 2014 amending Implementing Regulation (EU) No 680/2014 laying down implementing technical standards with regard to supervisory reporting of institutions according to Regulation (EU) No 575/2013 of the European Parliament and of the Council as regards asset encumbrance, single data point model and validation rules (OJ L 14, 21.1.2015, p. 1).

8 Collateral is reused "when a market participant, such as a bank, receives securities as collateral in one transaction and subsequently sells, pledges or transfers this collateral in a second transaction", FSB (2016).

9 Assets are measured at the carrying amount, whereas collateral is measured at fair value. Total collateral received and available for encumbrance refers to the sum of collateral received and reused (encumbered) and collateral – available for encumbrance – not yet reused (unencumbered).

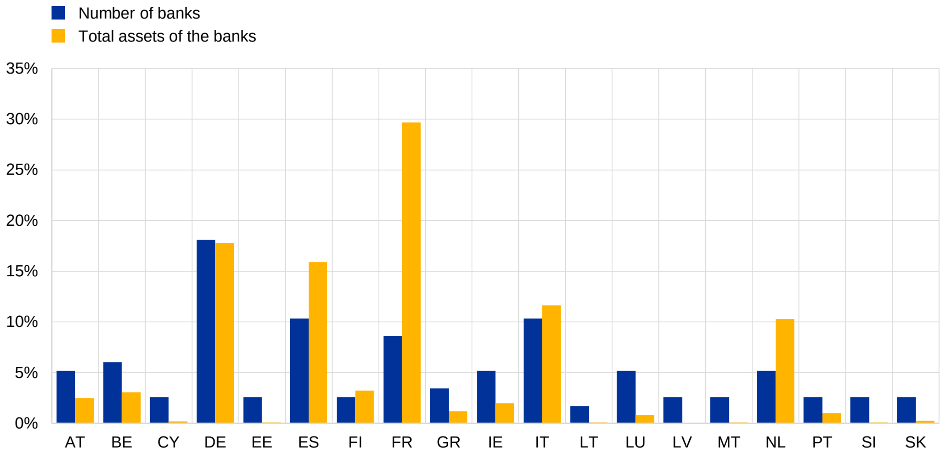
10 See Commission Implementing Regulation (EU) 2016/313 of 1 March 2016 amending Implementing Regulation (EU) No 680/2014 with regard to additional monitoring metrics for liquidity reporting (OJ L 60, 5.3.2016, p. 5).

encumbrance. The data were collected on a quarterly basis, with the exception of the data on contingent asset encumbrance, which were collected annually. The dataset contains data from all euro area significant institutions (SIs)[11]; this means that the total sample of SIs differs slightly across the years.

The SIs include a small number of subsidiaries. Some of these subsidiaries have a parent company in another country and are considered SIs as they are among the three largest credit institutions in the Member State concerned. As data are used at the highest level of consolidation, including these subsidiaries implies double counting, because the data are already included in the consolidated figures for the parent company. However, excluding these subsidiaries would mean that not all euro area countries were covered because in some countries (e.g. Slovakia) all SIs are subsidiaries. Aggregate figures in this paper do not include subsidiaries that are already captured by the consolidated figures for the parent entity. However, in order to provide sufficient information on all countries, country breakdowns do include these subsidiaries. The composition of the dataset by country in the fourth quarter of 2019 is shown in Chart 1.

Chart 1

Dataset composition by country in the fourth quarter of 2019



Note: These figures include subsidiaries. The total number of banks included in the country breakdown is 116.

The issuance of secured funding instruments varies across banks with different business models. To capture this heterogeneity, we consider the following business model categories:[12] (i) *small market lenders* that focus on domestic retail lending; (ii) *retail and consumer credit lenders*, which differ from the previous category in view of their larger size; (iii) *diversified lenders* that have a balanced exposure to both the retail and the wholesale sector; (iv) *corporate/wholesale lenders*, which differ from

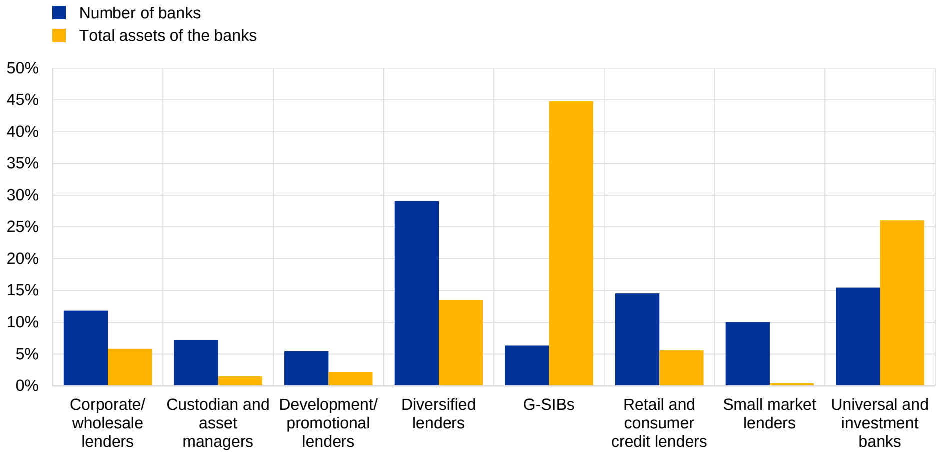
11 An institution is deemed significant if it fulfils any of the significance criteria related to (i) size, (ii) economic importance, (iii) cross-border activities, and (iv) direct public financial assistance. Significant institutions fall under the direct supervision of the ECB.

12 The banks in the sample are assigned to these categories according to a three-step process. In the first step, clear-cut cases are identified on the basis of quantitative rules on variables capturing income mix, size, lending exposure and funding mix. In the second step, any ambiguous cases not assigned in the first step are assigned through supervised machine learning using the results from step one as the training sample. In the third step, we cross-check the results with qualitative considerations and feedback from the Joint Supervisory Teams of each bank.

diversified lenders in their stronger focus on the corporate and wholesale sector, in terms of both clients and funding; (v) *development/promotional lenders*, state-owned banks financing projects that governments deem to be of public utility; (vi) *universal and investment banks* that are involved in both lending and non-lending-related fee business; (vii) *global systemically important banks (G-SIBs)*, large systemically important banks with a strong international focus, whose activity is typically broadly diversified; and (viii) *custodian and asset managers* that rely on non-lending-related fee business. The dataset composition by business model in the fourth quarter of 2019 is shown in Chart 2.

Chart 2

Dataset composition by business model in the fourth quarter of 2019



Note: These figures do not include subsidiaries. The total number of banks included in the business model breakdown is 112.

3 Asset encumbrance developments in the euro area

This section offers insights on the asset encumbrance dynamics of euro area banks. It shows the aggregate AE ratio over time and provides breakdowns at both country and business model level. It then illustrates the sources of encumbrance, the types of encumbered asset and AE ratios under stressed conditions.[13]

3.1 Asset encumbrance ratio

As shown in Chart 3, the aggregate AE ratio of euro area SIs has remained relatively stable, at around 25%, since the fourth quarter of 2014.[14] In the fourth quarter of 2019, it reached its historical minimum (24.1%) since data collection began. Underlying this, the decrease in encumbered assets and collateral (numerator) outpaced the decrease in total assets and collateral (denominator). The decreasing trend of the 95th percentile of the distribution can be linked to the introduction of stricter liquidity requirements as part of the Basel III regulatory package,[15] which forced banks with highly collateralised balance sheets to reduce their encumbrance. As shown in Chart A.1a in the Appendix, the AE ratio has followed a markedly downward trend for those banks that, in at least one observed period, were not compliant with the minimum liquidity coverage ratio (LCR), which supports this interpretation. Further evidence is that the 95th percentile of the AE ratio distribution flattens when those SIs are excluded from the full sample (Chart A.1b).

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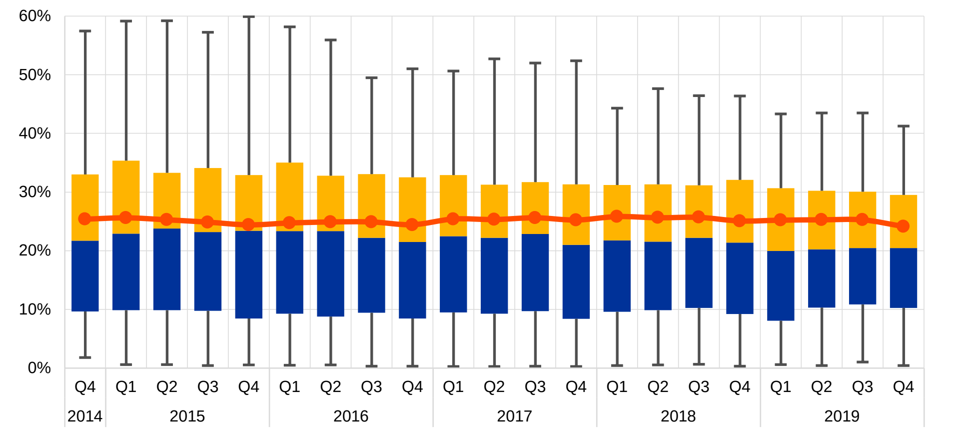
13 Descriptive analyses of asset encumbrance are also published by the EBA on an annual basis (see, for example, "EBA Report on Asset Encumbrance", EBA, 2019). Note however, that the EBA covers a sample of 181 banks across the EU, whereas our focus is on the significant institutions of the euro area.

14 The chart is based on a dynamic sample that includes all banks that are or have been SIs (154 SIs). The trend does not change if a constant sample is taken. The constant sample refers to the 88 SIs that provided data continuously in all quarters of the reference period. Note that all time-varying charts are based on the dynamic sample.

15 See BCBS (2013) and BCBS (2014).

Chart 3

Distribution of the AE ratios of euro area Sis



Note: This chart shows the weighted average (in red), the median, the 25th and 75th percentiles (boxes), and the 5th and 95th percentiles (whiskers). The weighted average is computed as the sum of the numerator over the sum of the denominator. Data are based on a dynamic sample of all euro area SIs at each reference period, excluding subsidiaries.

Five types of factor help to explain the developments in the aggregate AE ratio and differences across the euro area: (i) cyclical developments, (ii) country characteristics, (iii) business model specificities, (iv) bank-specific characteristics and (v) bank-specific events. After the descriptive analysis in this section, we further explore the drivers of asset encumbrance using a regression analysis (Section 4).

With respect to cyclical developments, the aggregate AE ratio rose significantly as a result of increases in central bank funding in countries more severely affected by the sovereign debt crisis in the period up to the end of 2015. In more recent years, banks in these countries – with the exception of Italian banks – have shown a downward trend in their AE ratios. From the fourth quarter of 2014 to the fourth quarter of 2019, Greek banks reduced their aggregate AE ratio from 26.0% to 19.7%, Irish banks from 27.6% to 12.0%, Spanish banks from 29.5% to 22.8%, and Cypriot banks from 26.7% to 7.2%. Italian banks, however, did not reduce their encumbrance after the sovereign debt crisis, with an aggregate AE ratio fluctuating around 29%. The dynamics of the AE ratio in these countries are shown in detail in Chart A.2b in the Appendix.

Turning to the second factor, country specificities help explain why asset encumbrance is higher in certain jurisdictions. AE ratios tend to be higher in countries characterised by a high share of repo financing or large covered bond markets. An example of the latter is Germany, which reported the highest aggregate AE ratio in the fourth quarter of 2019, at 31%. The aggregate AE ratio by country in the fourth quarter of 2019 is reported in Chart A.3 in the Appendix.

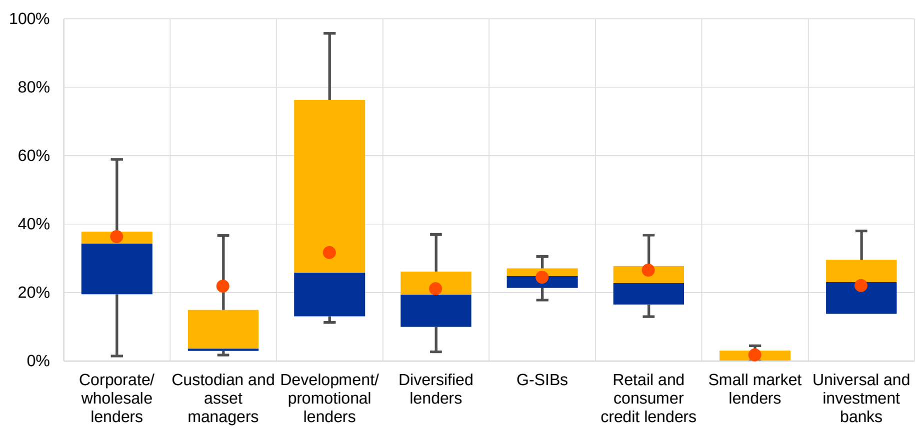
The third factor affecting AE ratios is business model specificities. Chart 4 shows the aggregate AE ratio by business model as of the fourth quarter of 2019. The lowest AE ratios can be found among small market lenders (1.7% in the fourth quarter of 2019). This is explained by the fact that these lenders are often owned by a foreign parent bank that provides funding without collateral requirements. Corporate/wholesale lenders can be found at the other end of the spectrum, with an aggregate AE ratio of 36.3% in the fourth quarter of 2019, given the lack of unsecured retail funding. The high dispersion of the ratio among development/promotional lenders can be explained by their different funding structures. For instance, for some development/promotional lenders in the sample covered bonds equate to 75% or more of their total funding, resulting in very high AE ratios, whereas other development/promotional lenders do not use covered bonds at all. It is important to note that country and business model effects should not be viewed in isolation. Some countries have a high occurrence of specific business models; similarly, some business models are concentrated in a few jurisdictions, which introduces a connection between country and business model aggregates. For instance, given that the banking systems in Estonia, Lithuania and Latvia are dominated by small market lenders, the AE ratio in these countries is very low (aggregate of 0.06% in the fourth quarter of 2019), in line with what we find for this business model.

As part of our empirical analysis in Section 4, we conducted an in-depth analysis of bank-specific factors. These include asset-side risk, the availability of high quality assets to be posted as collateral, and capitalisation.

Lastly, bank-specific events may affect AE ratios. For instance, an institution could experience an idiosyncratic shock that leads to unsecured funding becoming too expensive or not available at all. At the same time, secured investors would demand higher overcollateralisation. All of this would lead to a higher asset encumbrance level.

Chart 4

Distribution of the AE ratios of euro area SIs by business model in the fourth quarter of 2019



Note: This chart shows the weighted average (in red), the median, the 25th and 75th percentiles (boxes), and the 5th and 95th percentiles (whiskers). The weighted average is computed as the sum of the numerator over the sum of the denominator. Subsidiaries are excluded.

3.2 Encumbrance of central bank-eligible assets and collateral

The Statute of the European System of Central Banks[16] states that the lending activity of the Eurosystem is based on "adequate collateral". The notion of adequacy is determined by establishing eligibility requirements that regard – but are not limited to – asset type, asset marketability, type of issuer and credit score.[17] Under the credit score requirement, for instance, in order to be central bank-eligible the asset must be rated as investment grade. As explained in ECB (2015), the eligibility criteria imposed by the Eurosystem collateral framework were designed with the primary aim of mitigating credit, legal and operational risks, whereas market risks are mainly addressed by valuation haircuts rather than eligibility requirements.

In times of stress, investors are less willing to provide funding. This can cause unsecured funding to dry up and, ultimately, also affect the secured market. The role of the ultimate liquidity provider in stressed market conditions therefore lies with the central bank, which provides liquidity against collateral. This highlights the need for banks to have central bank-eligible assets available for encumbrance. An additional factor to consider is that in times of stress credit ratings may be downgraded, which reduces the pool of central bank-eligible assets.[18] The level of unencumbered central bank-eligible assets and collateral can thus be seen as a proxy for the assets and collateral that can effectively be encumbered in times of stress at a current credit rating. Chart 5 shows unencumbered central bank-eligible assets and collateral over total assets and collateral. The aggregate figures show a rising trend for available central bank-eligible assets and collateral, from 11.6% in the fourth quarter of 2014 to 14.8% in the same period of 2019.

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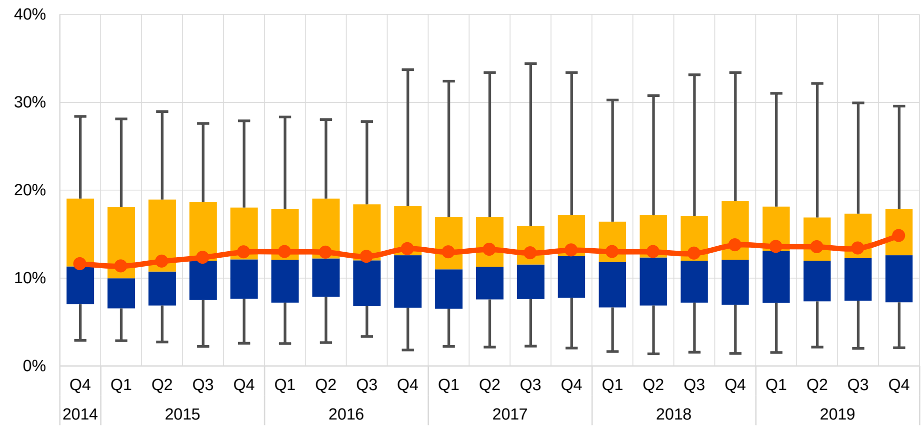
16 Protocol on the Statute of the European System of Central Banks and of the European Central Bank.

17 These are only some of the categories for which criteria have been established. See the ECB's website for further information on eligibility criteria.

18 It is interesting to note that this was not the case during the current crisis triggered by the coronavirus pandemic: on 22 April 2020 the ECB announced it would accept assets that had met collateral eligibility requirements on 7 April as long as ratings remained above a certain credit quality level, thus mitigating the effects of rating downgrades.

Chart 5

Distribution of the ratio of unencumbered central bank-eligible assets and collateral for euro area Sis



Note: This chart shows the weighted average (in red), the median, the 25th and 75th percentiles (boxes), and the 5th and 95th percentiles (whiskers). The weighted average is computed as the sum of the numerator over the sum of the denominator. Subsidiaries are excluded.

With respect to country differences, the highest ratio of unencumbered central bank-eligible assets and collateral is found in Cyprus, where it was 41.7% in the fourth quarter of 2019. This means that more than 40% of Cypriot banks' total assets and collateral can be used to obtain central bank funding. A considerable increase in the amount of central bank-eligible assets of Cypriot banks occurred between the second and third quarters of 2018, from 24.8% to 39.7% respectively. The explanation for this is that Cyprus's sovereign rating was below investment grade until September 2018. As a result, the domestic sovereign debt held by Cypriot banks could not be pledged as collateral for central bank funding and banks had to rely on other assets and collateral to access central bank facilities. As the Cypriot sovereign rating improved to investment grade in September 2018, these unencumbered bonds became eligible to obtain central bank funding, vastly increasing the amount of available central bank-eligible assets. In contrast, low ratios, which can signal difficulty to obtain funding in times of distress, are found in Greece (7.4%), Estonia (9.8%), Lithuania (3.5%) and Latvia (2.6%).[19] Regarding business models, development/promotional lenders report the highest availability of unencumbered central bank-eligible assets and collateral, at 23.2% in the fourth quarter of 2019. All the other business models range on aggregate between 10% and 15%.

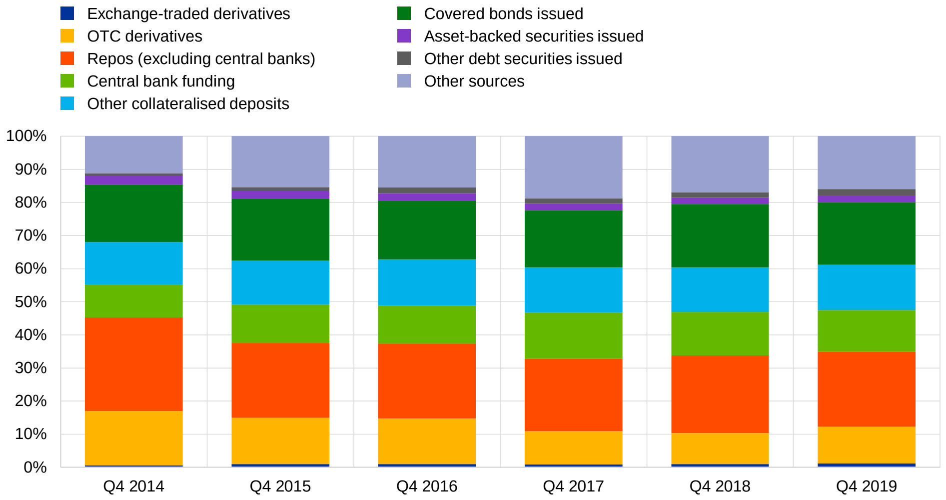
3.3 Sources of encumbrance and overcollateralisation ratios

The sources of encumbrance are those balance sheet liabilities for which collateral is posted. Chart 6 illustrates the shares of the different funding sources, based on the carrying amounts that lead to encumbrance.

[19] The lack of unencumbered central bank-eligible assets in Estonia, Lithuania and Latvia is accompanied by low levels of AE ratios.

Chart 6

Sources of encumbrance of euro area Sis



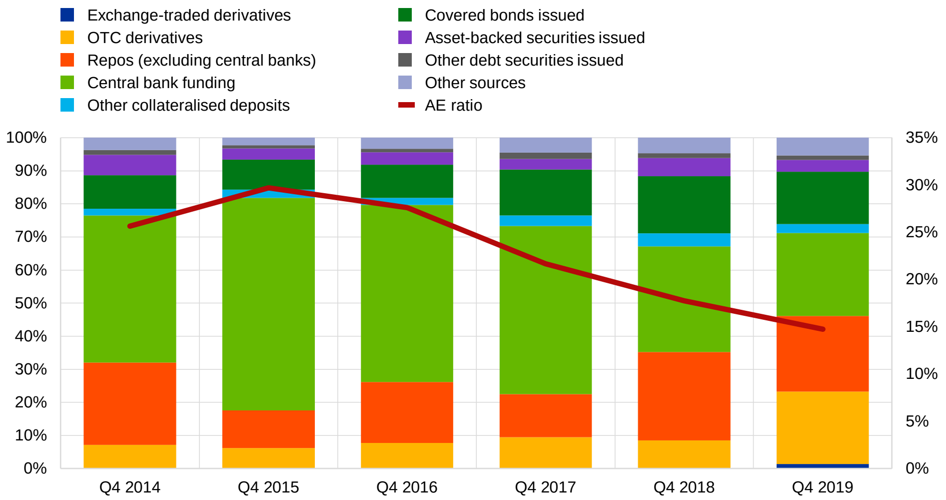
Note: This chart illustrates the funding sources for which assets have been encumbered. The percentages show the share of each funding source leading to encumbrance, with respect to all liabilities causing encumbrance. Subsidiaries are excluded.

The chart shows that since the fourth quarter of 2014 the share of OTC derivatives has decreased from 16.4% to 11.1%. Similarly, the share of repos has been decreasing since the fourth quarter of 2014; nevertheless, in the fourth quarter of 2019 repos still accounted for 22.5% of total encumbrance sources. In contrast, the share of central bank funding and other sources has increased since the fourth quarter of 2014. These aggregate figures are mainly driven by countries with large banking sectors, among which France, Germany, Spain, the Netherlands and Italy. Various other developments are therefore not shown in the aggregate picture. For example, a few countries strongly affected by the sovereign debt crisis (Cyprus, Greece, Ireland and Portugal) reported a high share of central bank funding as a source of encumbrance in the course of 2014 and 2015, but have reduced it in more recent years. Chart 7 illustrates this development and also depicts the aggregate AE ratio in these countries. Spain and Italy, however, also affected by the sovereign debt crisis, show an increase in the share of central bank funding as a source of encumbrance (as shown in Chart A.2 of the Appendix).

Chart 7

Sources of encumbrance and AE ratio of SIs in Cyprus, Greece, Ireland and Portugal

(left-hand scale: sources of encumbrance; right-hand scale: AE ratio)



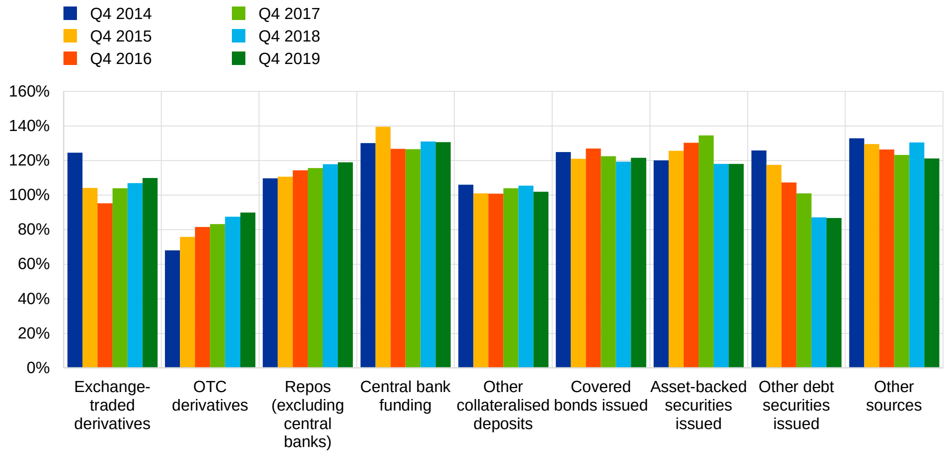
Note: This chart illustrates the funding sources for which assets have been encumbered. The percentages (left-hand scale) show the share of each funding source leading to encumbrance, with respect to all liabilities causing encumbrance. The dark red line represents the aggregate AE ratio (right-hand scale) in Cyprus, Greece, Ireland and Portugal. Subsidiaries are excluded.

The sources of encumbrance are related to banks' funding structures and differ across business models. An overview of sources of encumbrance by business model is shown in Chart A.4 of the Appendix. Small market lenders mainly take on encumbrance for the purpose of accessing ECB funding; development/promotional lenders and corporate/wholesale lenders have high shares of covered bonds. Corporate/wholesale lenders also encumber assets by means of other collateralised deposits, in addition to covered bonds. Universal and investment banks and G-SIBs have a more balanced funding structure which results in a strongly diversified encumbrance portfolio. Custodians and asset managers, which have nearly no conventional credit business, report securities lending as the predominant source of encumbrance.

Banks often post collateral in excess of the value of the secured funding received: the amount of encumbered assets generally exceeds the matching liabilities. Chart 8 depicts the overcollateralisation ratio, i.e. the ratio of the amount of encumbered assets and collateral over the funding obtained, across the different asset classes. The chart shows that other debt securities issued and OTC derivatives had the lowest aggregate overcollateralisation ratios, of, respectively, 87% and 90% in the fourth quarter of 2019. At the other end of the spectrum are central bank funding and other sources of funding, with aggregate overcollateralisation ratios of 131% and 121% respectively in the same period.

Chart 8

Overcollateralisation ratios for different funding sources

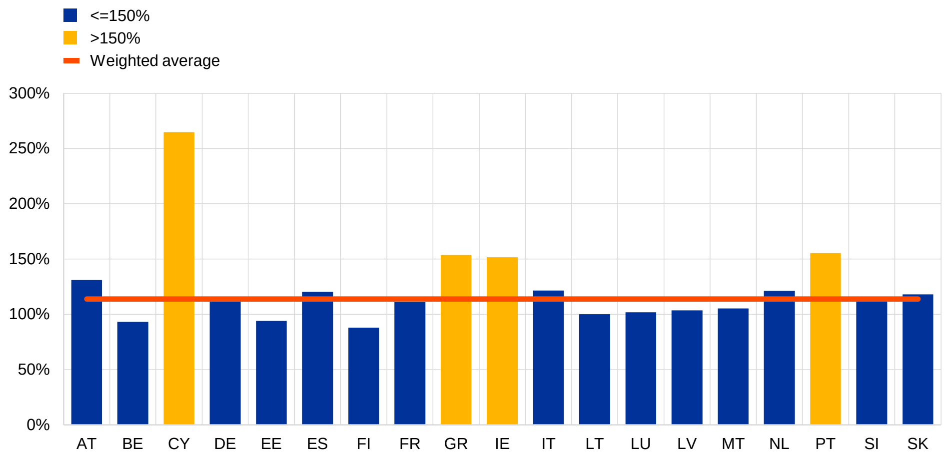


Note: This chart illustrates encumbered assets relative to matching liabilities for the different funding sources. Subsidiaries are excluded.

Overcollateralisation ratios across countries also differ widely, as illustrated in Chart 9. Countries in which institutions are more reliant on central bank funding, which as shown in the previous chart requires higher overcollateralisation, tend to report higher overcollateralisation ratios. Moreover, banks in countries more severely affected by the sovereign debt crisis may be perceived as riskier: this leads investors to require higher margins or to apply higher valuation haircuts. Chart 9 shows that the highest overcollateralisation ratios are found among Cypriot institutions, with an aggregate overcollateralisation ratio of 265% in the fourth quarter of 2019.

Chart 9

Aggregate overcollateralisation ratios across euro area countries in the fourth quarter of 2019



Note: This chart shows the aggregate overcollateralisation ratio by country. Countries with an aggregate overcollateralisation ratio of at least 150% are shown in yellow, while those with an aggregate overcollateralisation ratio of less than 150% are shown in blue.

In Greece, Ireland and Portugal the aggregate overcollateralisation ratio is more than 150%, at 153%, 151% and 156% respectively. The weighted average overcollateralisation ratio across all euro area SIs in the fourth quarter of 2019 was 114%.

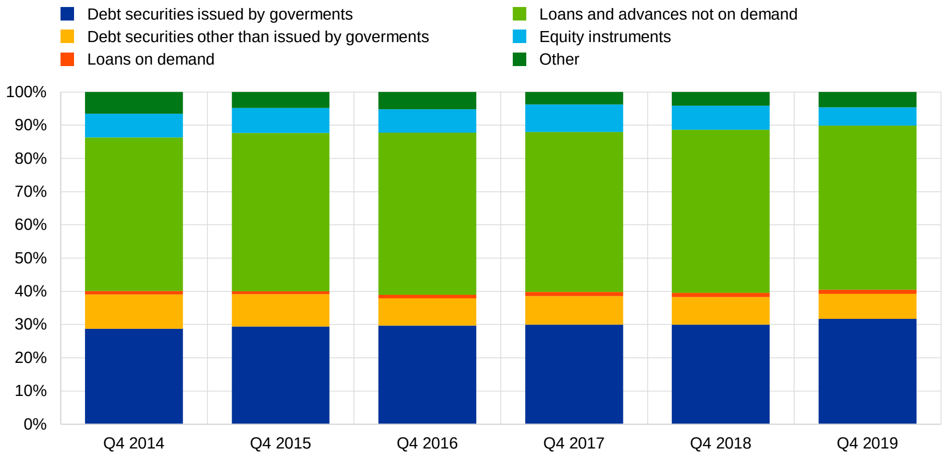
3.4 Types of encumbered asset

Chart 10 illustrates total amounts of encumbered assets and collateral broken down by asset class. Specifically, Chart 10a refers to all assets, whereas Chart 10b refers to central bank-eligible assets only.

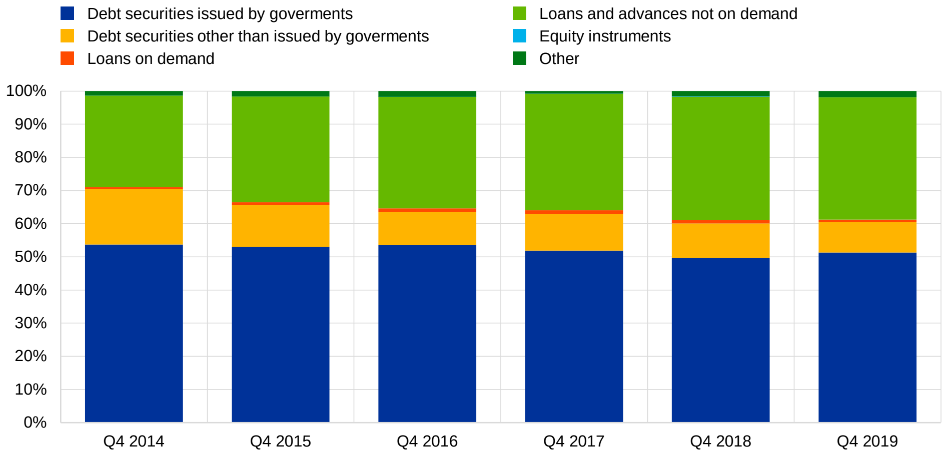
Chart 10

Encumbered assets and collateral received of euro area SIs – breakdown by asset class

a) Total encumbered assets and collateral received



b) Central bank-eligible encumbered assets and collateral received



Notes: These charts show encumbered assets and collateral by asset class. Chart 10a refers to all assets: it shows the share of encumbered assets and collateral by asset class as a percentage of total encumbered assets and collateral. Chart 10b refers only to central bank-eligible assets: it shows the share of central bank-eligible encumbered assets and collateral by asset class as a percentage of total central bank-eligible encumbered assets and collateral. Subsidiaries are excluded.

Loans and advances not on demand are the most widely used collateral, accounting in the fourth quarter of 2019 for 46% of aggregate total encumbered assets and collateral and 37% of aggregate encumbered central bank-eligible assets and collateral. If we link this to the sources of encumbrance, we see that these loans and advances are mainly used for covered bonds (39%), central bank funding (24%) and other collateralised deposits (20%). Government debt securities – mainly encumbered for repo funding (including central bank funding) – account for 51% of central bank-eligible encumbered assets and collateral and for 32% of all encumbered assets and collateral.

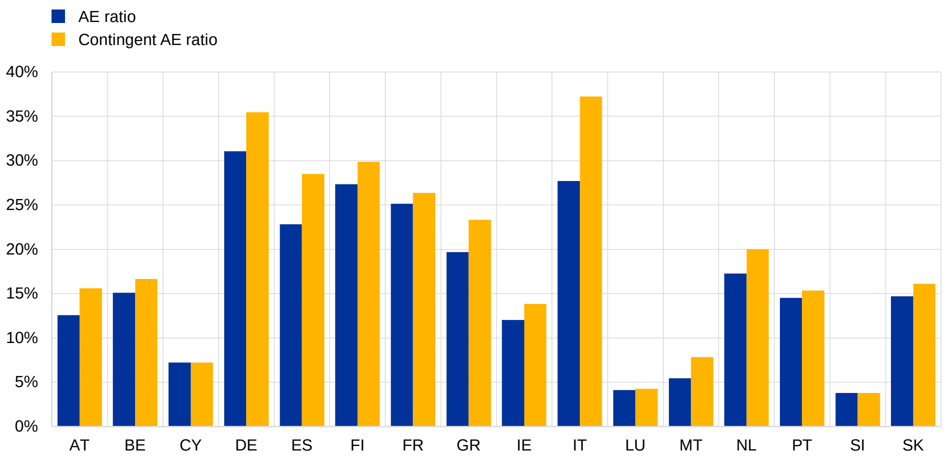
The types of encumbered asset were stable during the period considered.

3.5 Contingent asset encumbrance

As pointed out by the EBA,[20] it is not sufficient to only consider the actual level of encumbrance: the risk of additional encumbrance should also be taken into account. Euro area SIs are therefore required to report any additional encumbrance under stress on a yearly basis – one of the stress scenarios applied being a 30% decrease in the fair value of the encumbered assets. To keep the value of the collateral constant, institutions would have to encumber additional assets for existing transactions. The data show that on aggregate in the fourth quarter of 2019 this would increase the AE ratio from 24.1% to 27.8%. These data take into account the level of collateralisation, such that only the minimum level has to be maintained, as well as contractual requirements and threshold triggers.

Chart 11

Current AE ratios and contingent AE ratios across euro area countries



Notes: Reporting on contingent asset encumbrance is not required for institutions with total assets below €30 billion and a reported AE ratio of less than 15%. Countries without sufficient reporting institutions are therefore not included in the chart.

Current and contingent AE ratios across euro area countries are shown in Chart 11. It should be noted that the increase would bounce AE ratios to above 35% in Italy and Germany.

[20] See EBA/ITS/2013/04/rev1: EBA final draft implementing technical standards on asset encumbrance reporting under Article 100 of the Capital Requirements Regulation (CRR).

4 Econometric analysis of the drivers of asset encumbrance

The empirical analysis presented in this section has been developed from the viewpoint that identifying the determinants of asset encumbrance can support its supervision. In this regard two empirical works that follow this direction are worthy of mention. Jiménez et al. (2006) study the presence of collateral in bank loans to Spanish firms. Among other results, they find that riskier borrowers are more inclined to rely on secured funding. A more recent study by Di Filippo et al. (2020) obtains a similar result, with the focus on the European secured and unsecured interbank money market. Nevertheless, the literature still lacks a comprehensive assessment of the drivers of banks’ asset encumbrance. With a view to filling this gap, we investigate the driving factors of asset encumbrance through an econometric analysis that covers 117 SIs[21] using quarterly data from the fourth quarter of 2014 to the fourth quarter of 2019.

4.1 Economic priors: credit risk, collateral quality, sovereign-bank nexus, capitalisation, profitability

According to Ahnert et al. (2019), a bank’s privately optimal level of asset encumbrance is the result of a trade-off between the cheaper cost of secured funding on the one side, and the greater fragility caused by illiquidity and possible runs on unsecured debt on the other.

A number of mechanisms, set out below, have a potential impact on the way such a trade-off functions and thus affect the resulting level of asset encumbrance. The factors underlying these mechanisms (i.e. our selected candidate drivers of asset encumbrance) will be the subject of our econometric investigation.

Credit risk and asset deterioration could force banks to increase asset encumbrance

Secured debt holders are mostly insensitive to increases in the credit risk of the debt issuer because of the risk-mitigating function of the collateral posted. Asset encumbrance results in a shift of risk from secured to unsecured investors who, in the event of a default, will have fewer and weaker assets to satisfy their claims.

Hence, unlike secured investors, unsecured funding providers are sensitive to increases in credit risk and accordingly demand higher risk premia (see, for example, Di Filippo et al., 2020). Therefore, when credit risk increases, unsecured funding becomes more expensive and, in the worst cases, not available at all. In these

21 Depending on the specification, the sample might be reduced to a minimum of 115 SIs.

cases, the bank is forced to seek secured funding and the level of asset encumbrance rises.

Furthermore, when some encumbered assets become non-performing, they are replaced with performing assets that were previously unencumbered. A large presence of non-performing assets in the balance sheet exacerbates the structural subordination of unsecured investors. The risk arising from asset deterioration is completely absorbed by unsecured investors. Once again, discouraged by this risk concentration, unsecured funding providers tend not to roll over their investments and the bank is forced to switch to covered funding.

The availability of high quality collateral might increase the willingness or potential to raise secured funding

Secured funding is constrained by the availability of high quality assets to be posted as collateral. When collateral is not deemed adequate by the lender, assets' weaknesses are offset by applying higher haircuts, thus increasing the cost of funding faced by the borrower. Collateral quality magnifies the mitigation of interest expenses produced by secured funding. Thus, all things being equal, it is to be expected that the greater the amount of high quality assets available, the higher the level of asset encumbrance will be.

Moreover, a reserve of high quality unencumbered assets is needed to raise liquidity in periods of financial distress; therefore, banks with few high quality assets are forced to keep them unencumbered. This need, which underlies the liquidity requirements introduced in Basel III – LCR and net stable funding ratio (NSFR) –, corroborates the positive relationship that might exist between the availability of good collateral and asset encumbrance.

The sovereign-bank nexus might have an impact on banks' capacity to attract unsecured funding

The financial health of banks and sovereigns is heavily interconnected and gives rise to a sovereign-bank nexus. Dell'Ariccia et al. (2018) distinguish three main channels at the base of this nexus: (i) *the sovereign exposure channel*: banks hold large amounts of sovereign debt; (ii) *the safety net channel,* resulting from government guarantees*;* and (iii) *the macroeconomic channel:* the health of banks and governments affects and is affected by economic activity.

Therefore, a worsening of sovereign funding conditions could lead to an increase in banks' asset encumbrance as it reflects an increase in their risk, which can be viewed as a special case of credit risk and asset-side deterioration, as argued earlier in this section.

In addition, government debt securities are used extensively as collateral for covered funding. As illustrated in Chart 10, they account for 32% of all encumbered assets and 51% of central bank-eligible encumbered assets. For this reason, the sovereign exposure channel creates a linkage between sovereign funding conditions and collateral valuation (CGFS, 2011), especially with regard to central bank-eligible collateral. When government yields increase, the government debt securities held by a bank and posted as collateral depreciate, the depreciation being offset by posting additional collateral. This mechanism reinforces the connection between sovereign yields and asset encumbrance.

The relationship between asset encumbrance and capitalisation is expected to be non-monotonic – both poorly and well-capitalised banks have incentives to rely on asset encumbrance

To study the impact of capitalisation on asset encumbrance, two opposing effects need to be analysed.

First, as pointed out by the EBA in its 2016 annual report on asset encumbrance, banks with lower levels of capital are expected to encounter difficulties in attracting unsecured funding (EBA, 2016). Unsecured investors might penalise less capitalised banks by asking for higher risk premia, thereby forcing these institutions to rely on secured funding. The result is a negative relationship between capital and asset encumbrance.

Second, it could also be the case that better capitalised institutions have more capacity to increase their asset encumbrance. For these banks, the fragility arising from asset encumbrance is lower and therefore might be surpassed by the positive effects on profitability. In other words, given that their sound capital position would reduce the risk of runs by unsecured debt holders, these institutions might be able to increase their asset encumbrance in order to reduce their funding costs without compromising their liquidity conditions. In this case, the relationship between asset encumbrance and capital would be positive.

The potential ambiguity of the relationship between capital and asset encumbrance is one of the findings obtained from the theoretical model developed by Ahnert et al. (2019). In their paper, they find a non-monotonic relationship. Bearing this in mind, we investigate the existence of a convex relationship: for less capitalised banks the first effect is expected to outpace the second one, while for highly capitalised banks the second effect should outpace the first.

Less profitable banks could have reduced access to unsecured funding

Following a similar reasoning to the one proposed for capitalisation, in its 2016 asset encumbrance report the EBA states that less profitable banks, not attractive for unsecured funding providers, might be forced to rely on covered funding, thereby increasing their AE ratios (EBA, 2016). In other words, weak profitability could be another possible driving factor of asset encumbrance.

However, the relationship between asset encumbrance and profitability also acts in the opposite direction: since secured funding is generally cheaper, asset encumbrance reduces interest expenses, thereby improving profitability. The econometric evaluation of profitability is therefore hampered by reverse causality.[22] For this reason, we chose not to include profitability indicators in our econometric framework.

4.2 Variables

This section presents the variables adopted in our analysis, with a specific focus on the regressors chosen to capture the above-described mechanisms.

Asset encumbrance

In all the econometric specifications presented in this analysis, the dependent variable is a proxy for asset encumbrance. The natural choice to measure asset encumbrance is the AE ratio, already introduced in Section 2:

$$\text{AE ratio} = \frac{\text{encumbered assets} + \text{encumbered collateral}}{\text{total assets} + \text{total collateral}}$$

In the knowledge that banks' appetite to encumber central bank-eligible assets might differ from their appetite for asset encumbrance in general, we also consider a second measure, which disentangles the encumbrance of central bank-eligible assets:

$$\text{AE}_{\text{CB}}\ \text{ratio} = \frac{\text{encumbered CB eligible assets} + \text{encumbered CB eligible collateral}}{\text{total assets} + \text{total collateral}}$$

Our evaluation of the driving factors of asset encumbrance will have both the AE ratio and the AE_{CB} ratio as dependent variables.

Credit risk and asset deterioration

The ratio of NPLs to total gross loans (NPL ratio) is adopted as a proxy for credit risk. The NPL ratio captures the proportion of loans for which the bank will likely fail to collect the contractual principal or interest. As the level of NPLs contains information on the expected losses resulting from default by the bank's debtors, the NPL ratio is widely used in the literature as a proxy for credit risk (e.g. Dam and Kotter, 2012).

Moreover, the choice of an asset-based credit risk indicator allows us to directly capture the effects of asset deterioration on runs by unsecured debt holders. As explained above, the replenishment of non-performing collateral exacerbates the

22 Benmelech and Bergman (2009) discuss a similar problem encountered when measuring the effect of collateralisation on loan interest.

structural subordination of unsecured investors, who will only have riskier assets available to satisfy their claims.

The adoption of market-based proxies for banks' credit risk would give rise to reverse causality concerns. Previous empirical works show that asset encumbrance affects the value of banks' credit default swap (CDS) spreads (see, for instance, Banal-Estanol et al., 2019). Since we are exploring the opposite path – namely, the drivers of asset encumbrance –, we would encounter a problem of reverse causality if we used CDS spreads as a regressor. The same holds for any other market-based credit risk proxy that might be affected by CDSs which, in turn, are themselves affected by asset encumbrance.

Collateral quality

Collateral adequacy is a concept tailored to fit the desired characteristics that pledged assets should have in order to effectively mitigate the risk faced by the lender, i.e. collateral must ensure the total repayment of the debt to the lender if the borrower defaults. To fulfil its function, good collateral has (i) low credit risk; (ii) low market risk; and (iii) marketability, as well as low legal and operational risk. These qualities are described in more detail below.

Low credit risk means that collateral should have a low probability of default, if possible not correlated to that of the borrower. The risk mitigation function performed by collateral is compromised if its creditworthiness diminishes when the debt issuer defaults. Low market risk means that lenders should be protected against adverse changes in the collateral price that could occur during the time elapsing between the last collateral evaluation and the realisation of the collateral. Marketability, low legal risk and low operational risk refer to the ability of take ownership of, use and possibly sell the collateral without negatively affecting its value.

For the purpose of our analysis, collateral quality is captured well by central bank eligibility, as introduced in Section 3.2. To quantify the pledgeability of a bank's balance sheet, i.e. the ability to encumber assets to raise secured debt, we will consider the ratio of central bank-eligible assets and collateral over total assets and collateral, which we will refer to as the central bank-eligible ratio:

$$\text{CBE ratio} = \frac{\text{central bank eligible assets} + \text{central bank eligible collateral}}{\text{total assets} + \text{total collateral}}$$

Sovereign-bank nexus

The effects of the sovereign-bank nexus on asset encumbrance are measured by taking the 10-year domestic government yield. The sovereign yield captures both the country-specific effects on the cost of unsecured funding and price changes in government debt securities posted as collateral.

Taking the yield is econometrically equivalent to taking the spread against a risk-free rate, given that all our econometric specifications include time effects.

Capital

The adopted measure of capital is the common equity tier 1 (CET1) ratio.

However, as part of our robustness checks we also used a second measure of capital, the leverage ratio, which does not depend on the definition of risk-weighted assets.

Control variables

Our analysis adopts bank-specific and country-specific control variables, as described below.

Emergency liquidity assistance

Emergency liquidity assistance (ELA) comes into play when a national central bank in the Eurosystem provides central bank money to an institution facing liquidity issues.[23] Specifically, ELA allows financial institutions to access central bank funding with less restrictive requirements on the collateral posted, which does not need to be central bank-eligible.

This control is added to account for the different appetite for asset encumbrance that banks in need of ELA might display. ELA itself being a source of encumbrance, a positive relationship with the AE ratio is expected.[24]

Data on ELA are not available. However, when the amount of encumbered assets and encumbered collateral for central bank funding exceeds the amount of central bank-eligible encumbered assets and collateral received, we assume that ELA has been provided. Thus, by normalising for total liabilities, we obtain:

$$\mathrm{ELA} = \frac{\max\{0, \mathrm{EA_{CBF}} + \mathrm{CRR_{CBF}} - \mathrm{TA_{CB}} - \mathrm{CR_{CB}}\}}{\text{total liabilities}}$$

where EA_{CBF} is the total amount of assets pledged to raise central bank funding, CRR_{CBF} is the amount of collateral received and reused (encumbered) to obtain central bank funding, TA_{CB} is the amount of central bank-eligible assets and CR_{CB} is the total central bank-eligible collateral received.

23 See "Agreement on emergency liquidity assistance", ECB (2017).

24 Considering that ELA does not require central bank-eligible assets, a positive relationship is not expected ex ante when taking the AE_{CB} ratio as dependent variable.

Size

A size control is built by taking the logarithm of total assets. This choice, widely adopted in the literature (e.g. Gropp and Heider, 2010; Laeven et al., 2016), is particularly appropriate if we consider that the amount of total assets is right-tail distributed across our sample.

Income mix controls

To capture the main sources of income which contribute to net operating income, we build two additional controls, namely the share of net interest income in net operating income and the share of net fee and commission income in net operating income. The variables associated with these indicators are designated NII and NFCI respectively.

Time-invariant regressors: business model and country

As shown in Section 3, AE ratios are heterogeneous across countries and business models.

Country dummies are used to detect residual country effects not captured by government yields.

Similarly, business model dummies are adopted as a more granular alternative to the income mix controls introduced above.

4.3 Methodology

To obtain results that do not hinge upon a single set of econometric assumptions, we evaluate the regressors in a variety of regression set-ups, which can be broadly grouped into three categories.

First, static regressions with bank-specific fixed effects are performed. The equation of the model is:

$$Y_{it} = X_{it}\beta + \lambda_t + \alpha_i + \varepsilon_{it}$$

where Y_{it} is a measure of asset encumbrance, X_{it} is the vector of regressors, β the vector of coefficients of interest, λ_t the time effect, α_i the bank-specific fixed effect, and ε_{it} the residual.

Second, given the persistence of asset encumbrance measures, the data generating process is assumed to be first-order autoregressive. The following model is evaluated:

$$Y_{it} = \varphi Y_{it-1} + X_{it}\beta + \lambda_t + \alpha_i + \varepsilon_{it}$$

Y_{it-1} being the lagged dependent variable and φ the autoregressive coefficient. As pointed out by Angrist and Pischke (2009), this model, which includes both fixed effects and lagged dependent variables, relies on a weaker conditional independence assumption compared with the previous model, which includes only fixed effects. Here, however, we are relaxing our identifying assumption at the cost of stricter conditions for a consistent estimation. Given the challenges that arise from this trade-off, it makes sense to present the results in both the specifications to establish robustness against the underlying econometric assumptions.

This fixed effects dynamic model is evaluated with the quasi-maximum likelihood (QML) estimator developed by Hsiao et al. (2002), preferred in terms of efficiency to generalised method of moments (GMM) techniques. Nevertheless, a system-GMM estimation (see Blundell and Bond, 1998) is still performed as part of our robustness checks.

Third, we enrich the dynamics by recovering the effects of relevant time-invariant regressors. Given the heterogeneity of asset encumbrance measures among countries and business models, we aim to investigate the existence of possible statistically significant effects of these variables. To this end, we exploit the two-stage procedure developed by Kripfganz and Schwarz (2019): time-invariant variables are regressed on the residuals of a first stage estimation that includes only time-varying regressors. As a first stage result we take the QML estimation performed in the previous step.

Cross sectional heteroskedasticity of the residuals is assumed, therefore robust standard errors are adopted in all the specifications.

4.4 Results

The regressions presented in this section are grouped into three tables, according to the three different methodological set-ups described above.

Table 1 shows the results of the fixed effects static regressions, with the dependent variable being the AE ratio in the first four columns and the AE_{CB} ratio in the last four columns.

The significant and positive relationship between the NPL ratio and asset encumbrance is consistent with our prior that credit risk and asset deterioration hamper a bank's ability to attract unsecured funding. This result – in line with Di Filippo et al. (2020) – is based on the risk-monitoring behaviour of unsecured investors, who run when discouraged by the potential losses produced by non-performing assets. The encumbrance strategy of highly rated banks should be less sensitive to changes in NPLs, and the sensitivity of asset encumbrance to NPLs possibly dampened. To verify this reasoning, in regressions 4 and 8 the NPL ratio is interacted with the non-investment grade dummy, which takes a value of 1 for non-investment grade institutions and 0 for investment grade institutions.[25] The significance of the NPL ratio shown in the non-interacted model is now absorbed by the interacted term and we can conclude that the observed relationship between asset encumbrance and NPLs is mostly driven by non-investment grade institutions.

The central bank-eligible ratio shows a highly significant positive coefficient across all the specifications, in line with our hypothesis: the availability of central bank-eligible assets to be pledged as collateral has an impact on both the willingness and the capacity of a financial institution to access the secured market. The magnitude of this relationship is higher when the AE_{CB} ratio is chosen as dependent variable, which is an intuitive result.

Table 1

Results of the first econometric set-up: static model with bank fixed effects

	1 AE ratio	2 AE ratio	3 AE ratio	4 AE ratio	5 AE_{CB} ratio	6 AE_{CB} ratio	7 AE_{CB} ratio	8 AE_{CB} ratio
NPL ratio	0.493** (2.57)	0.510*** (2.66)	0.509*** (2.63)	-0.176 (-0.97)	0.371* (1.77)	0.350* (1.85)	0.353* (1.86)	-0.104 (-1.03)
NIG x NPL ratio				0.835*** (3.49)				0.557*** (2.91)
CBE ratio	0.186*** (3.76)	0.187*** (3.86)	0.186*** (3.82)	0.196*** (3.85)	0.325*** (5.46)	0.323*** (5.49)	0.325*** (5.53)	0.331*** (5.49)
CET1 ratio	0.0239 (0.36)	0.0243 (0.37)	-0.0474 (-0.18)	-0.0873 (-0.36)	0.0375 (0.66)	0.0316 (0.59)	0.158 (0.99)	0.131 (0.93)
CET1 ratio^2			0.0870 (0.33)	0.114 (0.47)			-0.153 (-1.00)	-0.135 (-0.96)
Gov. yield	2.778*** (5.88)	1.570*** (3.17)	1.568*** (3.13)	1.226*** (2.18)	1.391*** (3.39)	1.846*** (4.04)	1.850*** (4.07)	1.622*** (4.10)
Size	0.0423* (1.81)	0.0409* (1.77)	0.0408* (1.77)	0.0489** (2.24)	0.0237* (1.71)	0.0228* (1.68)	0.0230* (1.68)	0.0285** (2.10)
NII		0.00582 (1.33)	0.00592 (1.39)	0.00552 (1.44)		0.00704* (1.75)	0.00687* (1.75)	0.00660* (1.83)
NFCI		-0.00819 (-1.29)	-0.00833 (-1.35)	-0.00747 (-1.35)		-0.0103* (-1.77)	-0.0101* (-1.77)	-0.00951* (-1.82)
ELA		0.415*** (4.60)	0.414*** (4.58)	0.426*** (4.97)		-0.159** (-2.39)	-0.158** (-2.42)	-0.150** (-2.55)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,224	2,224	2,224	2,224	2,224	2,224	2,224	2,224
Num. banks	117	117	117	117	117	117	117	117
R^2	0.312	0.333	0.339	0.342	0.483	0.492	0.484	0.460

Note: t-statistics in parentheses; * p<0.1 **p<0.05 ***p<0.01.

Regarding capitalisation, neither the linear relationship nor the quadratic relationship show any significance in the fixed effects static models reported in Table 1.

The sovereign-bank nexus emerges as a driving factor of both asset encumbrance measures as the coefficient for the 10-year government yield is highly significant, with a positive sign in all the specifications.

[25] The non-investment grade dummy, referred to as NIG, is built by taking into account the worst default rating of those released by Fitch, Moody's, S&P and DBRS. When none of these credit rating agencies provides a default rating, the sovereign rating reduced by three notches is taken.

Finally, the coefficient for the size control variable shows the possible existence of a size effect: all else being equal, larger institutions are more likely to operate at high AE ratios.

All of the results described above remain stable when introducing an additional control for ELA. Given that ELA is a source of encumbrance of non-eligible assets and occurs when a bank lacks central bank-eligible assets, a positive coefficient is obtained with the AE ratio as dependent variable and a negative coefficient with the AE_{CB} ratio. Income mix controls do not affect the results.

Table 2 shows the regressions of the second econometric set-up, based on the assumption that the data generating process for asset encumbrance is autoregressive in nature. The first four columns have the AE ratio as dependent variable, while the last three columns have the AE_{CB} ratio. The NPL ratio and the central bank-eligible ratio are specified in first differences for easier interpretation of the respective coefficients. The results obtained in these dynamic regressions corroborate our assessment of the effects of non-performing assets, the availability of good collateral, the sovereign-bank nexus and size.

In contrast with the static framework, a highly significant convex relationship between the CET1 ratio and the AE ratio emerges (see regression 4). Less capitalised institutions might not succeed in attracting unsecured funding and be forced to resort to asset encumbrance. In this case, the lower their capital ratio, the more they tend to rely on asset encumbrance. Well-capitalised institutions, on the other hand, might be able to increase their asset encumbrance to reduce their funding costs without compromising their liquidity conditions, given that their sound capital position would reduce runs by unsecured debt holders. In this case, asset encumbrance is positively related to the level of capital. Nevertheless, the CET1 ratio remains non-explanatory in regression 7 when focusing on the encumbrance of central bank-eligible assets, with the AE_{CB} ratio being the dependent variable.

Once again, the introduction of additional controls, such as the ELA and income mix controls, does not affect the results.

Lastly, the possibility of evaluating time-invariant regressors allows us to: (i) estimate the coefficients on country dummies with the aim of detecting any residual country effect not already captured by government yields and (ii) evaluate the effects of business models by exploiting the business model classification[26]. Table 3 shows the coefficients on country dummies (regression 1) and on business model dummies (regression 2); in both cases, the first stage regression is the one in column 2 of Table 2.

[26] The business model classification was introduced in Section 2.

Table 2

Results of the second econometric set-up: first-order dynamic model with bank fixed effects evaluated using a QML estimator

	1 AE ratio	2 AE ratio	3 AE ratio	4 AE ratio	5 AE_{CB} ratio	6 AE_{CB} ratio	7 AE_{CB} ratio
L(AE ratio)	0.916*** (30.93)	0.909*** (29.16)	0.890*** (31.66)	0.894*** (34.68)			
L(AE_{CB} ratio)					0.895*** (34.25)	0.880*** (40.31)	0.886*** (39.01)
D(NPL ratio)	0.132** (2.21)	0.128** (2.12)	0.107* (1.88)	0.110* (1.93)	0.136** (2.45)	0.121** (2.18)	0.121** (2.22)
D(CBE ratio)	0.0898*** (4.04)	0.0888*** (4.02)	0.0887*** (4.16)	0.0856*** (4.03)	0.241*** (4.71)	0.237*** (4.76)	0.237*** (4.73)
CET1 ratio				-0.154*** (-2.64)			-0.0398 (-1.17)
CET1 $ratio^2$				0.158*** (2.88)			0.0366 (1.30)
Gov. yield	0.485*** (2.98)	0.432*** (2.99)	0.370** (2.42)	0.405*** (2.91)	0.210** (2.26)	0.181* (1.91)	0.197** (2.02)
Size			0.0127** (2.09)	0.00929* (1.80)		0.00836** (2.40)	0.00585 (1.30)
NII			0.00281** (1.99)	0.00292** (2.09)		0.00247** (2.00)	0.00240** (1.98)
NFCI			-0.00380* (-1.88)	-0.00395** (-1.97)		-0.00367** (-2.07)	-0.00351** (-2.04)
ELA		0.0281 (1.06)	0.0444* (1.73)	0.0368 (1.43)	-0.0173 (-0.96)	-0.0154 (-0.89)	-0.0174 (-0.96)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,974	1,974	1,974	1,972	1,956	1,955	1,953
Num. banks	116	116	116	116	115	115	115

Note: t-statistics in parentheses; * p<0.1 **p<0.05 ***p<0.01.

The coefficients for country dummies show statistically significant country-specific effects in line with the descriptive statistics shown in Section 3: all else being equal, the AE ratio is, on average, 2% higher in Germany, 1% higher in France and 1.6% higher in Italy. We interpret this evidence of country specificities as follows. Germany features a large covered bond market; France has a well-developed repo market; and the coefficient in Italy can be viewed as resulting from the large amount of central bank funding, which was not reduced after the end of the sovereign debt crisis.

The analysis also reveals statistically significant business model effects, confirming the descriptive findings set out in Chart 4 of Section 3: all things being equal, corporate/wholesale lenders are the business model with the greatest appetite for asset encumbrance.

Table 3

Results of the third econometric set-up: second stage regressions with time-invariant variables

The first stage results are taken from column 2 of Table 2. For the sake of brevity only the positive significant coefficients are reported

	1 AE ratio	2 AE ratio
DE	0.0201*** (2.62)	
FR	0.0120** (2.06)	
IT	0.0160** (2.49)	
Corporate/wholesale lenders		0.0192*** (2.98)
G-SIBs		0.00928*** (2.74)

Note: t-statistics in parentheses; * p<0.1 **p<0.05 ***p<0.01. Table A.1 in the Appendix show the full set of time-invariant regressors.

4.5 Robustness checks

To check the robustness of our results we performed additional regressions; the results are set out in Tables A.2 and A.3 of the Appendix.

Adjustment for central bank funding

As central bank funding requires collateral, it could be argued that our results for credit risk (as proxied by the NPL ratio) and collateral quality (as proxied by the central bank-eligible ratio) could be driven by central bank operations. For banks with high NPLs it might be advantageous to turn to central bank funding instead of tapping into the interbank market. Similarly, the availability of central bank-eligible assets may be a driving factor only of encumbrance arising from central bank funding, and not of asset encumbrance in general.

A robustness check against these possible mechanical relationships triggered by central bank funding is provided by re-evaluating the results with an adjusted measure of asset encumbrance, cleaned of central bank funding:

$$\mathrm{AE_{adj}\ ratio} = \frac{\text{encumbered assets} + \text{encumbered collateral} - \mathrm{EA_{CBF}} - \mathrm{CRR_{CBF}}}{\text{total assets} + \text{total collateral} - \mathrm{CBF}}$$

where EA_{CBF} is the amount of encumbered assets for central bank funding, CRR_{CBF} is the amount of collateral received and reused (encumbered) for central bank funding, and CBF is the outstanding amount of central bank funding.

The results are robust, as shown in regression 1 and regression 2 of Table A.2: the positive coefficients of the NPL ratio and the central bank-eligible ratio remain significant. Once again, the effects of asset deterioration are driven by non-investment grade banks (regression 2). Note also that the coefficient for the domestic government yield changes sign since government debt securities are a widely used type of collateral, especially for central bank funding (see Chart 10). When the yield increases, the government debt securities encumbered at the central bank depreciate and additional collateral is needed: the EA_{CBF}, and consequently the AE ratio, increase. At the same time, the pool of government debt securities available for additional non-central bank secured funding diminishes, hence the decrease in the AE_{adj} ratio.

Measure of the encumbrance of central bank-eligible assets

In addition to the AE_{CB} ratio, a second measure of the encumbrance of central bank-eligible assets was tested: the amount of encumbered central bank-eligible assets is measured as a fraction of the amount of central bank-eligible assets instead of total assets. We refer to this ratio as central bank collateral consumption:

$$\mathrm{CBCC} = \frac{\text{encumbered CB eligible assets} + \text{encumbered CB eligible collateral}}{\text{total CB eligible assets} + \text{total CB eligible collateral}}$$

The previous results are robust to this alternative measure of asset encumbrance (see regression 3 and regression 4 in Table A.2). Note that the central bank collateral consumption has a slightly different economic interpretation from the AE_{CB} ratio as it captures the appetite for encumbering central bank-eligible assets, given their overall availability.

The effect of the GACS securitisation scheme

The Italian government facilitated the securitisation of NPLs by introducing a guarantee scheme in 2016, named *Garanzia sulla Cartolarizzazione delle Sofferenze* (GACS). Since it was launched, the GACS scheme has enabled the securitisation of €70 billion in bad loans.

The substantial decline in NPLs for Italian banks with respect to the SSM average might produce an abnormal effect on the relationship between the NPL ratio and asset encumbrance. Since the data for securitised NPLs guaranteed by the GACS scheme are not available in our dataset, we controlled for a country-specific dummy which takes value 1 since the first quarter of 2016 only for Italian banks and 0 before that date, and in all other countries.

As shown in regressions 5, 6, 7, and 8 in Table A.2, the control for the GACS securitisation scheme does not affect the results.

Leverage ratio as a measure of capital, convex relationship evaluated also in first differences

As already anticipated in Section 4.2, the existence of a convex relationship between asset encumbrance and capitalisation is also investigated by taking an alternative measure of capital: the leverage ratio. Unlike the CET1 ratio, the leverage ratio does not account for the riskiness of bank assets. As shown in regression 3 of Table A.3, the quadratic relationship is robust when adopting the leverage ratio as a proxy for capital.

The relationship is also robust when evaluated in first differences instead of levels, both for specifications with the CET1 ratio and with the leverage ratio (respectively, regression 4 and regression 5 of Table A.3).

Size treated as time-invariant

The quarterly changes in banks' total assets are often negligible, implying that the within-variance of our size measure is relatively small. We therefore checked whether the size effect, which emerged in both the static and the dynamic set-ups, emerges if bank size is treated as time-invariant. To this end, we compute the within-average of the logarithm of total assets. Following the same procedure as adopted for the evaluation of country dummies and business model dummies, the time-invariant size coefficient is evaluated using the two-stage estimation of Kripfganz and Schwarz (2019). The size effect is confirmed for both the AE ratio and the AE_{CB} ratio (see Table A.3, regression 6 and regression 7 respectively).

GMM estimation of dynamic regressions

We check that our results on dynamic regressions do not depend on using the QML estimator. The results are robust to adopting a system-GMM estimator as shown in regression 1 and regression 2 in Table A.3.

4.6 Section conclusion

Asset encumbrance arises as the result of several mechanisms that either affect banks' access to unsecured funding or change their potential to exploit secured funding as a cost reduction tool. The analysis set out above offers insights to the drivers of asset encumbrance. Although we control for bank fixed effects and work with extensive robustness checks, we do not claim to establish causality. However, the coefficients are in line with hypotheses based on economic intuition, and in some cases theoretical models.

First, our analysis suggests two opposing asset-quality-based mechanisms that trigger increases in asset encumbrance: on the one hand, asset encumbrance increases for those banks that hold large amounts of high quality assets to be posted as collateral; on the other, higher amounts of low quality assets force financial institutions to switch from unsecured to secured funding. This switching is mainly driven by non-investment grade institutions, which are more sensitive to the credit risk induced by non-performing assets. The positive relationship between the NPL ratio and asset encumbrance measures suggests that asset encumbrance not only is a source of liquidity risk but should also be treated as a symptom of credit risk. These results hold for both the AE ratio and the AE_{CB} ratio.

In the dynamic specifications, a robust convex relationship between the AE ratio and capital emerges; the CET1 ratio, however, is non-significant in explaining the AE_{CB} ratio.

We establish a statistically significant positive relationship between domestic government yields and asset encumbrance; this suggests that the bank-sovereign nexus affects the funding conditions of financial institutions.

Finally, the evaluation of time-invariant regressors allows us to provide econometric evidence of the heterogeneity of asset encumbrance across countries and business models. All things being equal, Italian, French and German banks show higher AE ratios; as regards business models, the highest levels of encumbrance are found for corporate/wholesale lenders.

5 Asset encumbrance during a bank crisis

When a bank enters into a crisis, its AE ratio is likely to increase, for several reasons. First, as the bank is perceived as riskier, investors will react either by seeking higher yields for unsecured funding or by demanding collateral. Consequently, a bank that is entering a crisis and is therefore unable to tap into unsecured markets (or only at a very high cost) will resort to secured funding. Additional factors such as collateral depreciation, higher valuation haircuts and the need to substitute non-performing encumbered assets might increase the need for collateral, thereby producing additional pressure towards asset encumbrance.

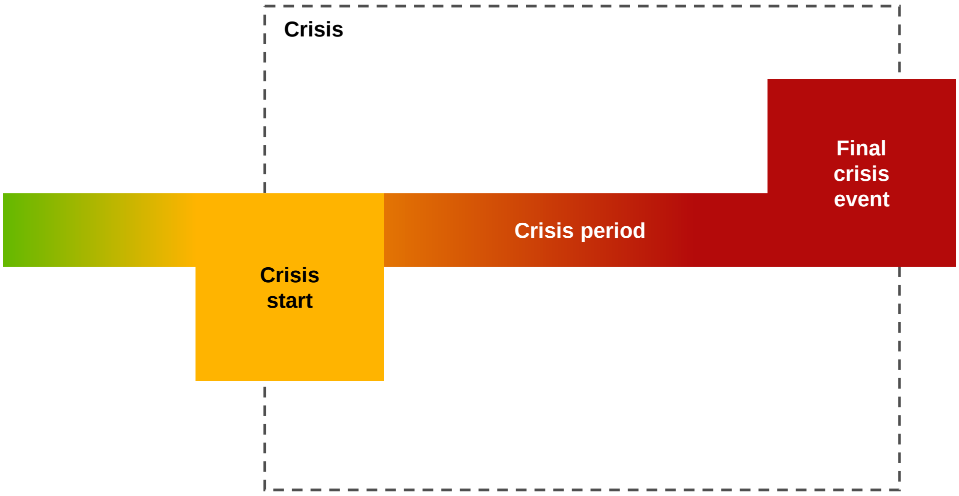
Increases in asset encumbrance might anticipate the start of the crisis, and thus have a predictive power. Specifically, unsecured debt holders (e.g. depositors) might run, in the expectation of future insolvency, while secured debt holders might increase overcollateralisation, for instance by demanding higher haircuts in anticipation of a credit rating downgrade of the financial institution.

This section studies asset encumbrance dynamics during a bank crisis from an event study perspective and lays the groundwork for the evaluation of asset encumbrance as a crisis predictor factor in Section 6. First, we define bank crises and provide an overview of the approach used to identify them. Second, we show asset encumbrance developments during two time windows that cover the start and the end of the crisis period.

5.1 Crisis identification

To explore the development of a bank's AE ratio during a crisis, the first step is to identify all the crisis cases in our sample. This, in turn, requires the identification of the actual crisis event and of the crisis period leading up to it (see Figure 1).

Figure 1
Visual representation of the crisis start, crisis period and crisis event



Note: A crisis is delimited by a crisis start and a final crisis event, which is marked by a formal intervention. We refer to the time elapsing between the crisis start and the final crisis event as "crisis period". The steps for the identification of a crisis are outlined in Figure 2.

To define a crisis, it is necessary to make working assumptions, for two main reasons. First, crisis events have very different features and so are not easily captured by a unidimensional definition. Second, a final crisis event may be preceded by a long or short crisis period that could start either abruptly or slowly. A sudden start to a crisis, marked for instance by unexpected news or events, is more easily identifiable; by contrast, when a crisis begins slowly, the starting point might be hard to define.

5.1.1 Identifying the final crisis event

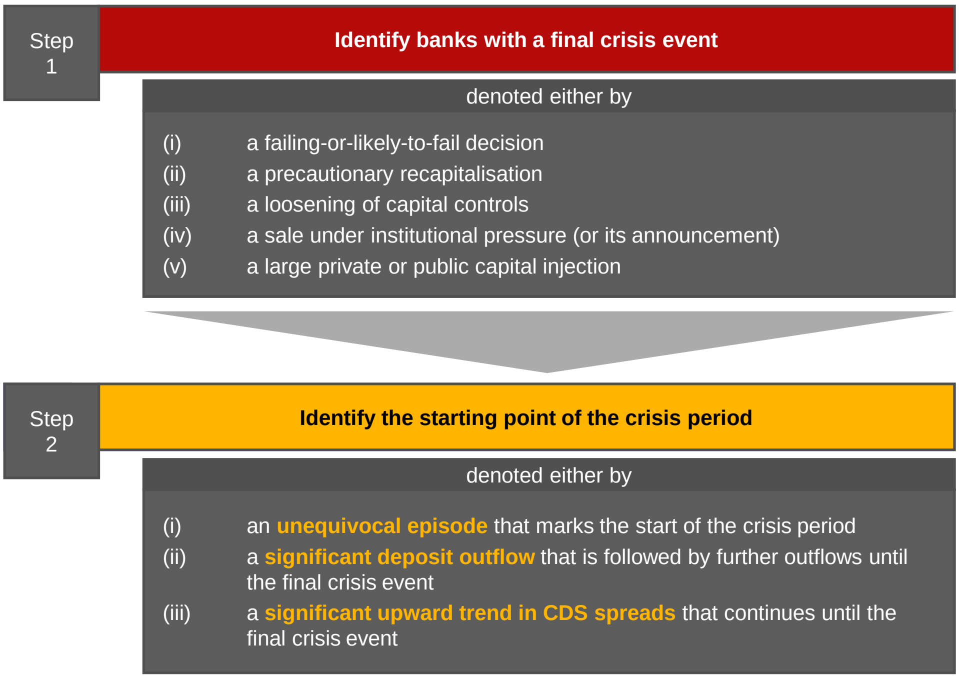
Since crisis events are heterogeneous and it is often not clear whether a bank has experienced an actual crisis or not, only crisis events that are identified by a single criterion are included in the crisis sample. Specifically, the working criterion adopted is that there should be a formal intervention that resolves the crisis, so we refer to "final crisis event" and "end of crisis" interchangeably. As outlined in the first step of Figure 2, to capture different features of banks' financial distress, our crisis definition accounts for a broad set of final crisis events: (i) a failing-or-likely-to-fail decision,[27] (ii) a precautionary recapitalisation, (iii) a loosening of capital controls, (iv) (an announcement of) a sale under institutional pressure, or (v) a large private or public capital injection.

5.1.2 Identifying the start of the crisis period

To identify the start of the crisis, the second step of Figure 2 is followed.

[27] See Article 32 of the Bank Recovery and Resolution Directive.

Figure 2
Steps for crisis identification



Note: The diagram outlines the main steps followed to build the sample of crisis banks and identify the underlying crisis periods.

First, we take the list of banks for which a final crisis event has been identified. Second, we investigate whether: (i) there is any one unequivocal episode that marks the start of the crisis period, (ii) there is a deposit run, or (iii) there is a significant upward trend in the bank's CDS spreads.

5.1.3 Results

The methodology described above is applied to a sample of 67 SIs with quarterly data ranging from the fourth quarter of 2014 to the third quarter of 2017. Asset managers and custodians and development/promotional lenders are excluded in view of the specific nature of their business model. Subsidiaries are also excluded as their survival probability largely depends on the survival probability of the parent institution. The distribution of banks by country is shown in Table A.4 in the Appendix. Of the 67 SIs, 12 crisis banks are identified, together with their corresponding crisis starting points, periods and events. Seven of the crisis banks experienced a clear event that triggered the crisis period, six experienced a deposit run, and six had a significant increase in CDS spreads.

5.2 Aggregate dynamics of asset encumbrance during a crisis

Aggregate dynamics of asset encumbrance around the start and end of the crisis are shown below.

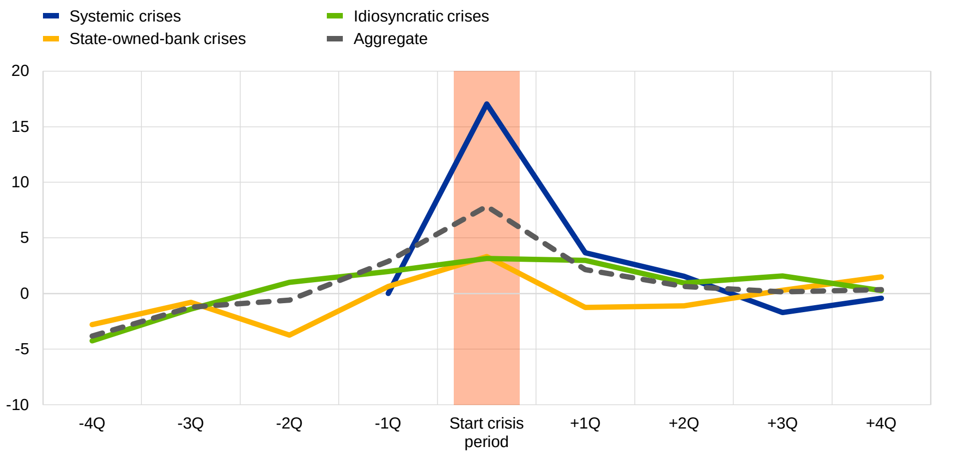
5.2.1 Quarterly changes in the asset encumbrance ratio around the start of the crisis

For the 12 crisis banks identified, the AE ratio increases prior to the start of the crisis period, by 9 percentage points on aggregate, as shown by the dashed grey line in Chart 12. This rising trend starts two quarters before the beginning of the crisis, with the largest change being observed in the quarter when the crisis starts.

The magnitude of the upward movement of the aggregate AE ratio around the start of the crisis differs across crisis types. Chart 12 shows a breakdown into *systemic crises*, *state-owned-bank crises* and *idiosyncratic crises*. The first category refers to banks facing a wider systemic banking crisis; the second to crisis banks that are (directly or indirectly) mostly state-owned; and the third to banks experiencing a crisis in isolation. The chart shows that systemic crises result in the most dramatic increase in asset encumbrance. The AE ratio of banks with an idiosyncratic crisis reacts more strongly than the ratio for state-owned banks, but less strongly than the ratio for banks experiencing a systemic crisis.

Chart 12

Quarterly change in the AE ratio (in percentage points) at the start of the crisis



Note: The chart shows quarterly changes in the AE ratio, e.g. a value of 1.0 in quarter -2Q denotes an increase of 1.0 percentage points from quarter -3Q to quarter -2Q. The results are based on a sample of 12 identified SSM crisis banks.

5.2.2 Asset encumbrance ratio, deposits and central bank collateral consumption

On aggregate, around the start of the crisis period asset encumbrance levels increase while deposits flee (Chart 13a). This inverse movement denotes a replacement of unsecured funding with secured funding, triggered by a run on deposits. In addition, the central bank collateral consumption[28] (Chart 13b)

[28] The central bank collateral consumption is defined as the ratio of central bank-eligible encumbered assets and collateral over the total amount of central bank-eligible assets and collateral.

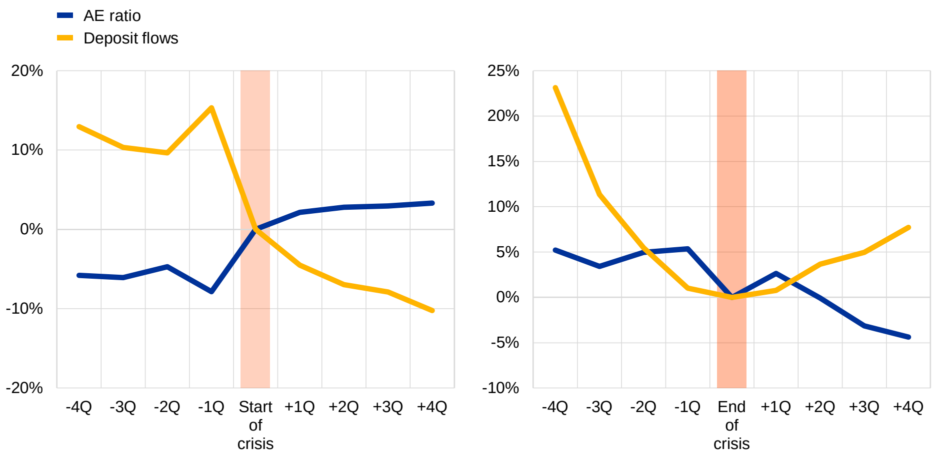
increases in line with the AE ratio, indicating that deposit flows are mainly offset by central bank funding.

Around the end of the crisis, the movement in deposit flows is much stronger than the movement in asset encumbrance (Chart 13a). In the last four quarters leading up to the crisis event, 25% of deposits evaporate, while the AE ratio starts to decrease. This indicates that, in spite of the strong deposit outflow, no additional covered funding is granted to banks that are close to the crisis event. The central bank collateral consumption (Chart 13b) fluctuates before the crisis event and decreases after it, along with the AE ratio, as the crisis solution to some degree alleviates the pressure on the bank's funding conditions. Note, however, that for surviving banks not all deposits return (within four quarters) after the crisis event.

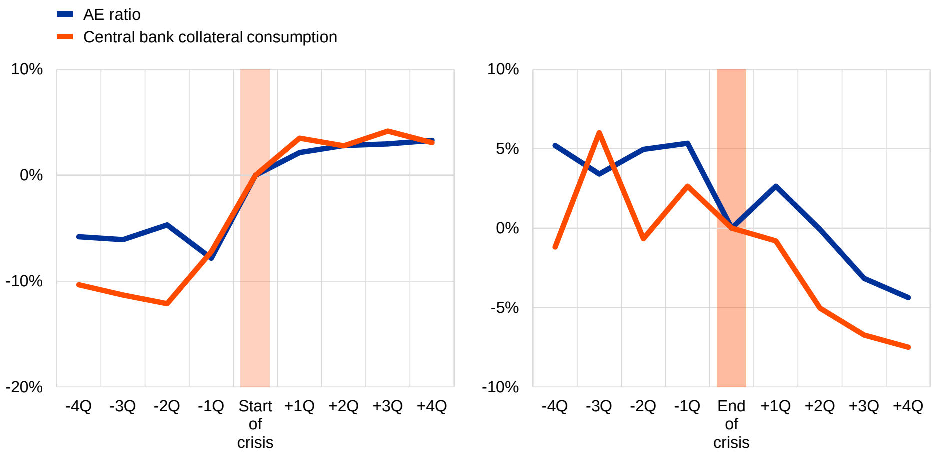
Chart 13

The development of the AE ratio, deposit flows and the central bank collateral consumption

a) AE ratio and deposit flows



b) AE ratio and central bank collateral consumption



Notes: The blue line shows the average absolute change (in percentage points) of the AE ratio with respect to its value at the start of the crisis (both left-hand panels) and at the end of the crisis (both right-hand panels). The yellow line shows the average percentage change in the amount of deposits with respect to the value at the start of the crisis (upper left-hand panel) and at the end of the crisis (upper right-hand panel). The red line shows the average absolute change (in percentage points) of the central bank collateral consumption (i.e. the ratio of encumbered central bank-eligible assets and collateral over central bank-eligible total assets and collateral) with respect to its value at the start of the crisis (lower left-hand panel) and at the end of the crisis (lower right-hand panel).

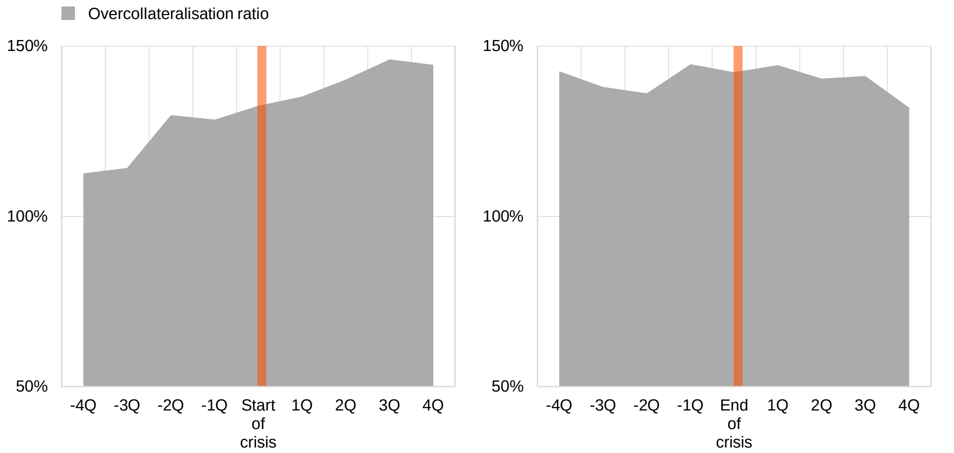
5.2.3 Overcollateralisation

As illustrated in Chart 14, overcollateralisation rises at the start of the crisis and remains high thereafter. The overcollateralisation ratio reaches just over 100% four quarters before the crisis, which suggests that the funding received almost equals the collateral pledged. In the quarters around the start of the crisis, however, collateral haircuts rise, meaning that more collateral has to be pledged for the same amount of funding or, equivalently, less funding is received for the same amount of collateral.

At the end of the crisis overcollateralisation stabilises at just below 150% and remains high after the crisis event.

Chart 14

The development of the overcollateralisation ratio



Note: The chart shows the average overcollateralisation ratio (i.e. the ratio of encumbered assets and collateral over the amount of matching liabilities) at the start of the crisis (left-hand panel) and at the end of the crisis (right-hand panel).

5.3 Section conclusion

Based on univariate analysis, we can conclude that the AE ratio generally rises around the start of a crisis. The dynamics, however, differ by type of crisis, with the 9 percentage point aggregate increase mainly being driven by systemic crises.

The increase in secured funding is intended to offset heavy deposit outflows and coincides with higher central bank collateral consumption. Eventually, around the end of the crisis, central bank funding is reimbursed and the AE ratio declines accordingly.

Finally, overcollateralisation rises sharply at the start of the crisis and remains high until at least four quarters after it ends (for surviving banks). This implies that crisis banks have to pledge much more collateral than they receive in funding (even after the end of the crisis).

6 Asset encumbrance as an early warning indicator

As the previous section shows that asset encumbrance dynamics already change prior to a crisis, asset encumbrance may serve as an early warning indicator. This section empirically tests the information content of various asset encumbrance indicators in the context of an early warning model.

6.1 A two-step approach to test the usefulness of asset encumbrance in an early warning model

The evaluation of the information content of asset encumbrance-related indicators in the context of an early warning system follows the widely established literature.[29] We conduct our analysis in two layers.

- **Multivariate layer:** we examine whether asset encumbrance measures, employed in conjunction with other financial indicators, help to classify crisis periods more effectively with respect to non-crisis periods. To determine whether asset encumbrance can be a predictive factor in crisis incidents, we adopt a logistic regression for the crisis cases illustrated in Section 5. The process involves two main phases. First, through a random forest approach, we test the importance of a variety of banks' financial variables, including asset encumbrance indicators. Second, we estimate the logit model with the selected variables and evaluate the fit. In this way, the hypothesis that asset encumbrance variables may predict a distress event is tested, while taking into account various other factors such as liquidity, profitability and asset quality.
- **Univariate layer:** this layer determines the threshold beyond which each informative variable selected in the previous layer (e.g. the quarterly changes in the AE ratio) maximises crisis detection. This is achieved by a grid search on all potential values in the empirical distribution of the variable in question, according to a criterion that summarises false alarms and hit rates.

6.1.1 Sample and tested variables

The dataset coincides with the one adopted for the event study analysis in Section 5. It includes quarterly data ranging from the fourth quarter of 2014 to the third quarter of 2017 for 67 SIs, 12 of which experienced a crisis that was detected following the methodology illustrated in the previous section. To this end, we adopt the same broad definition of crisis events as used in the previous section, which is not limited

[29] See Kaminsky et al. (1998), Kaminsky and Reinhard (1999), Borio and Drehmann (2009), Betz et al. (2014), Alessi and Detken (2014) and Lang et al. (2019).

to bankruptcies, liquidations and defaults.[30] In the context of our early warning system, a broad definition of crisis has two advantages. First, a more comprehensive definition of crisis events ensures a conservative approach, which is typical of supervisory activity. Second, it increases the number of crisis observations included in the model, thereby improving classification performance, given that bank failures in Europe have been extremely rare.[31]

In this analysis, 38 variables are tested with regard to their usefulness as early warning indicators. These variables cover four categories: profitability, asset quality, liquidity, and encumbrance and counterbalancing capacity. Table 4 sets out all the indicators tested. The predictors employed are used on a six-month lag[32] so as to avoid issues related to contemporaneous variables and achieve an adequate forecast horizon for supervisory purposes. The tested variables are included both in levels and in first differences in order to examine these two aspects separately.[33]

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30 As stated in Section 5.1.1, the final crisis events taken into account are the following: (i) a failing-or-likely-to-fail decision, (ii) a precautionary recapitalisation, (iii) a loosening of capital controls, (iv) (an announcement of) a sale under institutional pressure, or (v) a large private or public capital injection.

31 There are several cases in the literature on early warning systems where a broad definition of crisis was preferred for analogous reasons, see for instance Betz et al. (2014), Bräuning et al. (2019) and Ferriani et al. (2019).

32 The suffix "_2" in variable names denotes a two-quarter lag.

33 The prefix "d_" in variable names means that the variable is taken in first differences. Note that deposit variables are included only in first differences.

Table 4

Set of tested indicators

	Indicator	Variable name
Profitability	Cost of funds (interest expenses over financial liabilities)	cost_of_funds
	Cost of risk (loan impairments over gross loans)	cost_of_risk
	Cost-to-income ratio (operational expenses over net income)	cti_ratio
	Return on equity	roe
	Return on assets	roa
Asset quality	Coverage ratio (provisions over NPLs)	cov_ratio
	Texas ratio	texas_ratio
	NPL ratio	npl_ratio
Liquidity	Loan-to-deposit ratio	ltd
	Household deposits	dep_hh
	Non-financial corporations' deposits	dep_nfc
	Other financial corporations' deposits	dep_ofc
	Credit institution deposits	dep_cr
	Government deposits	dep_gv
	Central bank deposits	dep_cb
Encumbrance and counterbalancing capacity	AE ratio	ae
	Unencumbered central bank-eligible assets over total central bank-eligible assets	ae_cb_elig_ava
	Encumbered central bank-eligible assets over total central bank-eligible assets	ae_cb_elig
	Overall counterbalancing capacity	cbc_ov
	Short-term counterbalancing capacity	cbc_st
	Unencumbered central bank-eligible assets and collateral over total assets	ae_cb_elig_ava_col_debt
	Unencumbered assets over total assets	ue_on

Notes: The suffix "_n" is added to the variable name to indicate a lag of n quarters. The prefix "d_" is added to the variable name to indicate that the variable is taken in first differences. Deposit variables are included only in first differences, whereas all the other variables are included both in levels and in first differences. In this way, starting from these 22 indicators, we obtain a pool of 38 variables.

6.2 The multivariate analysis

The multivariate analysis described below allows us to check whether asset encumbrance measures could help predict a distress event, while taking into account various other factors associated with banks' financial health.

6.2.1 Oversampling

Given the low frequency of observations (quarterly) and the limited occurrence of crisis events, the issue of the imbalanced nature of this dataset arises (1.5% of crisis cases). To resolve the issue of imbalanced data, the class distribution is altered before obtaining any classification estimates, employing the random oversampling examples (ROSE) algorithm of Menardi and Torelli (2014). The algorithm generates new artificial cases that are *similar* to rare crisis observations (oversampling), while at the same time decreasing frequent non-crisis observations (undersampling). Using this algorithm, a balanced sample of 70% non-crisis and 30% crisis cases is generated.

6.2.2 Random forest set-up

To reduce the dimensionality space, i.e. focus the analysis on the most informative variables, we employed random forest variable importance. The random forest method (Breiman, 2001) involves bootstrapping and aggregating a multitude of decision trees. Starting from a broad set of variables, each of the trees in the forest is grown on a randomly selected subset of indicators and bank quarters. On the basis of updated input variables, each of the trees in the forest classifies a given bank as either in a vulnerable state or not. An extensive cross-validation procedure is performed to select a series of entailed hyperparameters, including the maximum depth of the generated trees, the minimum leaf-node size to perform a split, the size of sub-sample for building the classification trees and the variables considered in each split.

6.2.3 Variable selection using importance measures and taking the correlation structure into account

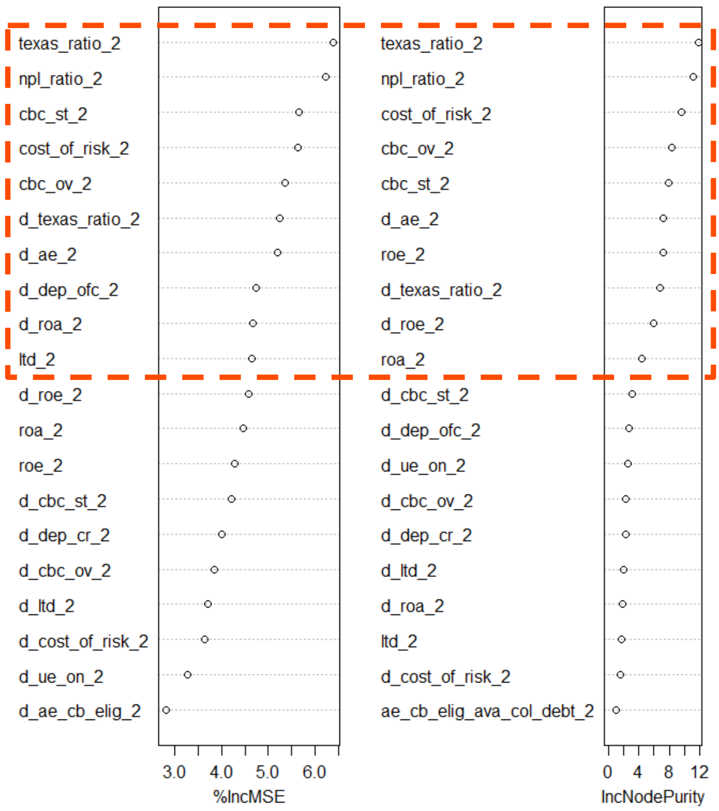
Variable importance captures the effect that a variable has on the predictions of a model and is measured by calculating the increase of the model prediction error after permuting the observations of the variable. Variables are considered important if permuting their values increases the model error, and unimportant if it leaves the model error unchanged. By comparing the losses in the overall performance of the model associated with the randomisation of the observations of each variable, the relative importance of each covariate can be deduced and ranked. Chart 15 shows the most important variables ranked according to two measures of relative performance: mean squared error and node purity[34].

[34] Node purity refers to homogeneity, i.e. the presence of crisis cases, at a split.

Chart 15

Variables selected using the random forest variable importance method

Six-month forecast horizon



Notes: Variable importance is employed to classify crisis periods with respect to non-crisis periods, following a random forest approach. The variables have been ranked according to two different performance measures: mean square error (left-hand column) and node purity (right-hand column). The red box highlights the ten most important variables according to each measure, leading to a set of 13 different variables (most variables in the red box appear in both columns).

The first ten most important variables are selected from both rankings (see red box in Chart 15), leading to the identification of the 13 different variables reported in Table 5.

Taking the asset encumbrance indicators included in the model, the change in the AE ratio has significant predictive power for bank crises over a six-month horizon. This leads to the intuition that it is not the level of asset encumbrance, but rather abrupt increases in it, that signals whether a bank is liable to fail or not.

The set of selected variables is further narrowed by examining their collinearity structure.[35] This makes it possible to avoid the overlapping of signals from variables that are similar in nature, while also obviating multicollinearity issues in the regression standard error estimates.

[35] The multicollinearity analysis of the most important indicators and the forecast evaluation are conducted on 80% of the initial sample to avoid overfitting issues.

Table 5

Summary of the variables selected using the random forest variable importance method and collinearity analysis

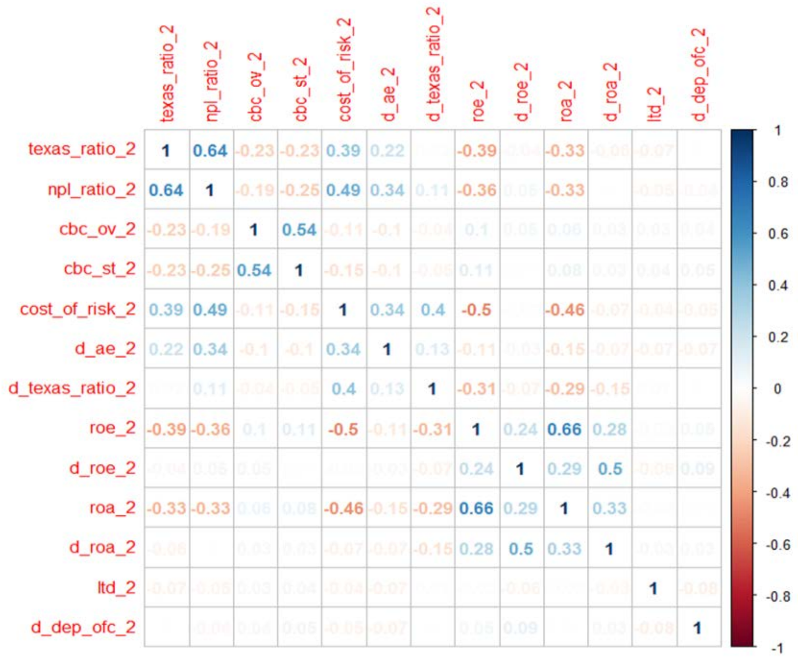
Indicators selected using the variable importance method	Dropped after the collinearity analysis
Texas ratio (texas_ratio)	No
NPL ratio (npl_ratio)	No
Overall counterbalancing capacity (cbc_ov)	No
Short-term counterbalancing capacity (cbc_st)	Yes
Cost of risk (cost_of_risk)	Yes
Change in the AE ratio (d_ae)	No
Change in the Texas ratio (d_texas_ratio)	No
Return on equity (roe)	No
Change in the return on equity (d_roe)	No
Return on assets (roa)	Yes
Change in the return on assets (d_roa)	Yes
Loan-to-deposit ratio (ltd)	No
Change in deposits from other financial corporations (d_dep_ofc)	No

Notes: 13 different variables were selected using the variable importance method. Four variables are dropped because of collinearity with other variables.

Chart 16

Independent variables correlation matrix

Six-month forecast horizon



Notes: Correlation coefficients of the 13 variables selected using the random forest importance method. The variables dropped from the analysis because of multicollinearity are: roa_2 (0.66 correlation with roe_2); d_roa_2 (0.50 correlation with d_roe_2); cbc_st_2 (0.54 correlation with cbc_ov_2); cost_of_risk_2 (-0.50 correlation with roe_2).

Taking into account the collinearity matrix presented in Chart 16, four variables are dropped, as outlined in Table 5. They are: the ROA variables, given their correlation with the ROE variables; short-term counterbalancing capacity, given its 0.54

correlation with overall counterbalancing capacity; and cost of risk, given its -0.50 correlation with the ROE. Notwithstanding their 0.64 correlation, both the Texas ratio and the NPL ratio are kept, because they are both statistically significant in the logit specification.

6.2.4 Logit model using the selected variables

The nine variables selected using the above-described procedure are now adopted to evaluate a logit model whose output is displayed in Table 6.[36]

The results of the logit model show that poor asset quality (as measured by the NPL ratio and the Texas ratio), combined with low profitability and increasing asset encumbrance, signal a high probability of a bank crisis.

Table 6
Logit model based on indicators selected from the variable importance and multicollinearity selection process

Six-month forecast horizon

Coefficients	Estimate	Standard error	Z-value	Pr(>|z|)	
(Intercept)	-4.596	0.444	-10.353	0.000	****
texas_ratio_2	0.026	0.004	7.091	0.000	****
npl_ratio_2	0.069	0.012	5.901	0.000	****
cbc_ov_2	-0.003	0.002	-1.549	0.121	
d_ae_2	0.030	0.016	1.871	0.061	*
d_texas_ratio_2	0.015	0.010	1.582	0.114	
roe_2	-0.020	0.006	-3.109	0.002	***
d_roe_2	-0.027	0.006	-4.167	0.000	****
ltd_2	-0.001	0.002	-0.568	0.570	
d_dep_ofc_2	-0.001	0.017	-0.083	0.934	
AIC	432.58				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

As a next step, to select the most appropriate specification without losing predictors with explanatory power, a stepwise regression process is followed. This requires an iterative procedure that starts from an evaluation of the general model that includes all the selected variables. In each subsequent step, non-significant variables, according to the Akaike information criterion (AIC), are dropped and the model is re-estimated. Table 7 provides the regression results after the two variables with the lowest explanatory power are omitted.

[36] The coefficients and standard errors which appear in the estimation outputs reported in Table 6 and in Table 7 were obtained from the full sample data.

Table 7
Logit model based on indicators selected from the variable importance and multicollinearity selection process after stepwise regression

Six-month forecast horizon

Coefficient	Estimate	Standard error	Z-value	Pr(>|z|)	
(Intercept)	-4.706	0.405	-11.629	0.000	****
texas_ratio_2	0.026	0.004	7.087	0.000	****
npl_ratio_2	0.069	0.012	5.909	0.000	****
cbc_ov_2	-0.003	0.002	-1.493	0.135	
d_ae_2	0.030	0.016	1.883	0.060	*
d_texas_ratio_2	0.015	0.010	1.558	0.119	
roe_2	-0.020	0.006	-3.085	0.002	***
d_roe_2	-0.026	0.006	-4.152	0.000	****
AIC	418.29				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

The results in Table 7 confirm that asset quality, profitability and asset encumbrance carry a significant crisis prediction power. It should be underscored that it is not the level of asset encumbrance, but rather abrupt increases in encumbrance, that signal whether a bank is likely to experience a crisis.

As we are focusing here on the specific contribution of asset encumbrance-related variables, we perform a log-likelihood test on the variable d_ae_2, which confirms the better model fit when the variable is included. The reduction in the AIC (and accordingly in log-likelihood) leads to a p-value of less than 5%, which signifies that the model fit effectively decreases when the encumbrance indicator is removed.

6.2.5 Performance and backtesting

The model shows high classification accuracy: the AUROC[37] metric of the logit model, when examined in the 12 original crisis cases (not the oversampled dataset), is close to 96%, indicating adequate fit.

To evaluate the performance of the model, we infer an optimal cut-off threshold that is used to map the predicted probabilities of a bank crisis event onto binary predictions.

37 AUROC refers to “area under the receiver operating characteristics” curve.

Table 8
Classification performance of the model

Six-month forecast horizon

	Predicted as non-crisis cases	Predicted as crises cases	Signal	Rate
Non-crisis cases	622	78	False alarm	11%
Crisis cases	2	10	Hit rate	83%

Notes: Classification performance of the model evaluated using the original sample (67 SIs from Q4 2014 to Q3 2017). This includes 712 quarterly observations, 12 of which are the starting quarter of a crisis period.

Specifically, we seek a threshold that minimises the total weighted prediction loss, whereby the cost of not predicting a crisis (false-negative) is given a higher weighting than the cost of a false alarm. From the classification performance of the model summarised in Table 8 we deduce that, by accepting an 11% false alarm rate (78 cases out of 700), we succeed in correctly predicting 83% of historical crisis events (ten cases out of 12).

6.3 The univariate analysis

The signalling approach is a one-factor analysis to find an appropriate threshold or cut-off for an indicator beyond which a crisis event is highly likely to occur. A lax threshold value is likely to capture all of the crises but is also likely to generate many false alarms (high type I error). A very strict threshold value, on the other hand, will have the opposite effect (high type II error). The following univariate analysis focuses on the indicators selected using the random forest variable importance method as outlined above.

To obtain the optimal cut-off, a grid search across all potential values of the indicators is conducted and the optimal cut-off is the one minimising the error loss function proposed by Borio and Drehmann (2009):

$$L = \theta \cdot type\ I + (1 - \theta) \cdot type\ II \qquad \theta \in (0,1)$$

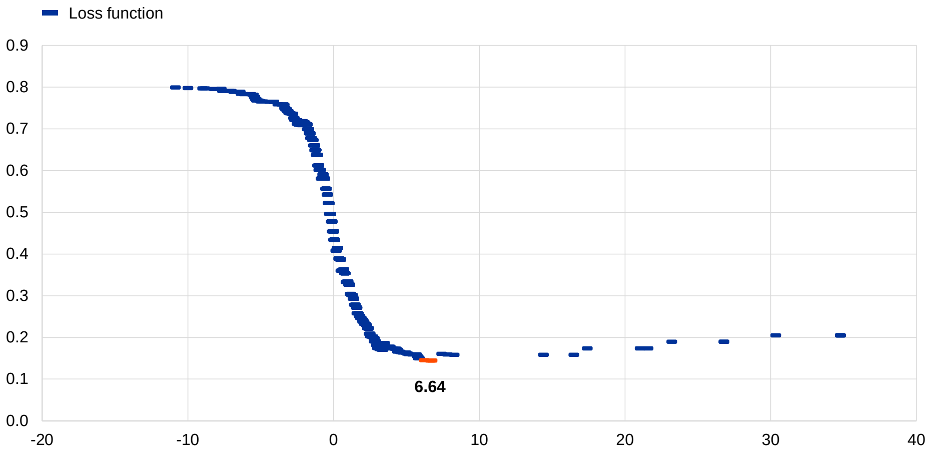
Theta is selected to be 0.8, so as to impose more weight to missing crises relative to falsely signalling them. The plot of the loss function (y-axis) based on different cut-offs (x-axis) for the change in the AE ratio is shown in Chart 17.

Chart 17

Loss function (y-axis) for the change in the AE ratio based on different cut-offs (x-axis)

Six-month forecast horizon

(x-axis: cut-off for the quarterly change in asset encumbrance (d_ae) measured in percentage points)



Note: A 6.64 percentage point quarterly increase in the AE ratio minimises the loss function that weights type I and type II errors in crisis prediction.

In Table 9, the optimal thresholds recognised from the signalling approach are presented, specifying whether they are upper or lower thresholds, meaning that a crisis is signalled if it surpasses or falls below the threshold value respectively. The errors, based on the loss function, are in line with the logistic regression standard errors. This confirms that asset quality indicators, along with profitability measures and asset encumbrance measures, provide a strong signal of a bank crisis. As regards asset encumbrance, an abrupt increase in the AE ratio of 6.64 percentage points provides a strong signal for an upcoming bank crisis over a six-month horizon. This means that a bank makes a marked shift from unsecured to secured funding sources, which suggests an environment of low trust on the part of counterparties in the funding market.

Table 9

Optimal thresholds recognised from the signalling approach

Six-month forecast horizon

Variables	Crisis threshold	Up/Low	Error
Texas ratio (%)	109.37	Up	0.108
NPL ratio (%)	23.4	Up	0.108
Return on assets (%)	-0.97	Low	0.141
Cost of credit risk (%)	2.39	Up	0.119
Return on equity (%)	-11.25	Low	0.146
Loan-to-deposit ratio (%)	137.9	Up	0.242
Change in Texas ratio (p.p.)	3.23	Up	0.138
Change in return on assets (p.p.)	-0.45	Low	0.158
Change in AE ratio (p.p.)	6.64	Up	0.144
Change in return on equity (p.p.)	-8.01	Low	0.150

Notes: For ten of the 13 variables selected using the random forest variable importance method, thresholds that minimise the loss function have been computed. As this is a univariate analysis (i.e. each variable is evaluated separately), there is no multicollinearity issue. This allows us to show the results for variables that were previously excluded from the logit model. The results for short-term counterbalancing capacity, overall counterbalancing capacity and the change in deposits from other financial corporations are omitted as their thresholds are non-informative.

6.4 Robustness checks

We employ a twofold strategy to examine the robustness of the results: (i) we alter the crisis definition; and (ii) we reduce the forecast horizon from six to three months.

Varying crisis definition

First, to ascertain that the results are independent of the crisis specification, we alter the crisis definition in three different ways:

- R1: drop any crisis cases linked to a systemic crisis event from the sample;
- R2: drop any idiosyncratic crisis cases from the sample;
- R3: drop any crisis cases that occurred at state-owned banks from the sample.

The estimation results for the logit model are shown in the Appendix (see Tables A.5, A.6 and A.7). While the estimated coefficients are robust for all the alternative crisis definitions, some differences occur in the statistical significance of certain indicators. Specifically, the coefficient for the change in the AE ratio is significant in the R2 and R3 specifications, but loses significance in R1 as the standard error of the coefficient increases. Asset quality metrics and profitability metrics continue to provide a good indication of upcoming bank crisis events under all three crisis definitions.

Varying early warning horizon

As a second step in examining the robustness of the analysis, the forecast horizon is changed from six to three months.[38] The results are shown in the Appendix (see Charts A.5-A.7 and Tables A.8-A.12). Using the random forest variable importance method, we can deduce that there are no remarkable differences in highly important indicators compared with the six-month horizon. Of the encumbrance indicators included in the model, the change in the AE ratio and both measures of counterbalancing capacity have significant crisis-predictive power on a three-month horizon. An additional encumbrance indicator emerging on this shorter term horizon is the change in the ratio of unencumbered assets to total assets.

Once again, based on the collinearity analysis (see Chart A.6), the ROA is dropped in view of its correlation with the ROE. Other variables are also dropped: short-term counterbalancing capacity, in view of its correlation with overall counterbalancing capacity; cost of risk, in view of its correlation with the NPL ratio; and changes in the amount of unencumbered assets to total assets, in view of their correlation with changes in the AE ratio.

Coefficient signs, standard errors and model fit are in line with the six-month horizon results. The change in the AE ratio emerges as highly significant in statistical terms in all the alternative crisis definitions. The same applies for the univariate analysis, where the NPL ratio and the Texas ratio, along with profitability measures and increasing asset encumbrance, provide a strong signal of a potential bank crisis, including in the short term. The errors calculated in the univariate framework are lower for the three-month horizon, given the lower degree of uncertainty. We can deduce that a 5.87 percentage point rise in the AE ratio leads to an increased probability of a bank crisis in the next three months. A similar signal can be obtained from a reduction in the unencumbered-to-total assets ratio (-7.76 percentage points).

6.5 Section conclusion

The analysis described in this section establishes that asset encumbrance carries additional information in the context of a multivariate early warning model with other variables associated with banks' financial health, as suggested in the event study of Section 5. We provide three pieces of evidence for the contribution of the variable "change in AE ratio" (d_ae) to the predictive power of the model:

1. the random forest measures of variable importance (mean squared error and node purity) indicate additional information content in the quarterly change in the AE ratio when used jointly with other variables;

2. in the logistic regression multivariate setting, the change in the AE ratio remains statistically significant both after a stepwise selection process and under a series of robustness checks;

[38] The suffix "_1" in variable names denotes the one-quarter lag.

3. a log-likelihood test for the removal of the asset encumbrance variable leads to a reduction in the AIC, implying a p-value of less than 5%, which signifies that the model fit effectively reduces when the encumbrance indicator is removed.

Furthermore, by means of a signalling approach, optimal cut-off points are identified for each of the variables, considering type I and type II errors. This analysis shows that an abrupt increase of 6.64 percentage points in a bank’s AE ratio can be interpreted as a warning signal of an upcoming bank crisis.

A change in asset encumbrance adds to the signalling quality of an early warning system, at both the three and six-month warning horizon. The robustness of the results is further checked against changes in the definition of bank crisis.

7 Conclusion

High AE ratios can make banks more vulnerable to crises. One of the main consequences of asset encumbrance is structural subordination, meaning that pledging assets to secured creditors shifts risks to unsecured creditors. Structural subordination increases fragility and, as it might trigger runs on unsecured debt, makes the issuer less resilient to shocks. Additionally, a high AE ratio means that only a small pool of assets remains available to raise secured funding, thereby hampering banks' ability to raise liquidity, especially in periods of financial downturn.

Aggregate figures for the AE ratio in the euro area do not give immediate cause for concern as the aggregate ratio has remained relatively stable since the inauguration of the SSM, and recently reached its historical minimum. However, considerable heterogeneity exists across banks, business models and countries, as shown in our descriptive analysis.

We are able to provide a better understanding of developments in asset encumbrance by analysing its driving factors. We find indications that credit risk, as captured by poor asset quality, is associated with higher asset encumbrance. This effect is mostly driven by low-rated banks. The effect of another asset-quality-based mechanism runs counter to this: the availability of high quality collateral favours higher AE ratios. In addition, the bank-sovereign nexus is also relevant to asset encumbrance, as it affects the cost of unsecured funding and the market valuation of government debt securities, widely adopted as collateral. Moreover, according to our analysis the relationship between asset encumbrance and capitalisation appears to be non-monotonic. Lastly, we find a size effect and a number of business model and country specificities. The core findings are very robust, notably against changes in econometric specification, the introduction of additional control variables and variations in how asset encumbrance is measured.

By identifying banks that have experienced a crisis, we are able to detect common asset encumbrance-related patterns prior to, during and following a crisis. More concretely, asset encumbrance tends to increase in the lead-up to a crisis and decline after the crisis has been resolved. These patterns suggest that changes in the AE ratio carry predictive power in the early stages of a crisis situation, which leads us to consider asset encumbrance in the context of early warning systems.

Lastly, we show that asset encumbrance is useful as an early warning indicator and carries additional information when used jointly with other relevant variables to predict bank crises. Specifically, we employ a random forest approach followed by the construction of a logit model with a stepwise regression process to determine important variables in predicting a bank crisis. Both parts of this statistical procedure indicate that asset encumbrance contributes additional information and improves the model fit. Subsequently, using a signalling approach, optimal cut-off points are identified for each variable, taking into account type I and type II errors. This analysis shows that an abrupt increase in a bank's AE ratio of 6.64 percentage points provides a signal of an upcoming bank crisis over a six-month horizon.

The insights assembled in this paper highlight the need for supervisors to keep asset encumbrance indicators under close scrutiny in their day-to-day supervision work, and enable them to better interpret the ratios in the context of historical trends and against country and business model peers. We contribute to the economic understanding of what drives asset encumbrance. Lastly, we establish empirically the reaction of asset encumbrance to a crisis and the usefulness of the concept in the context of an early warning system. Taken as a whole, this paper contributes to a more conscious and sophisticated use of asset encumbrance indicators in banking supervision, while at the same time providing a stimulus for further research on the topic.

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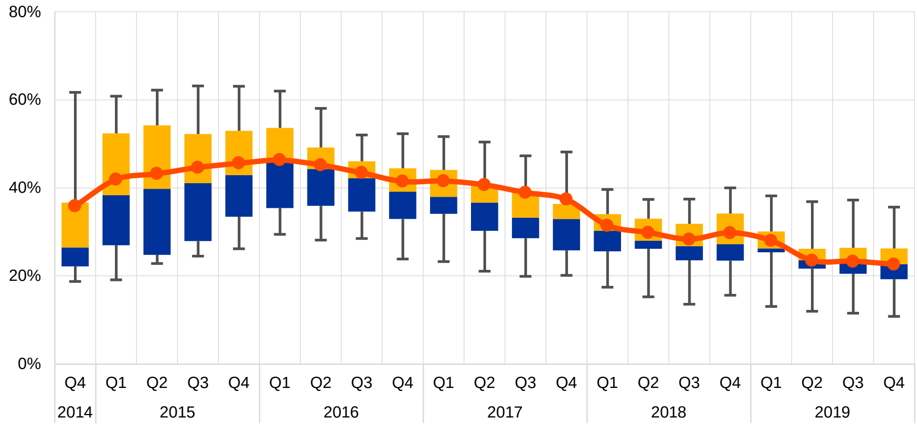
Appendix

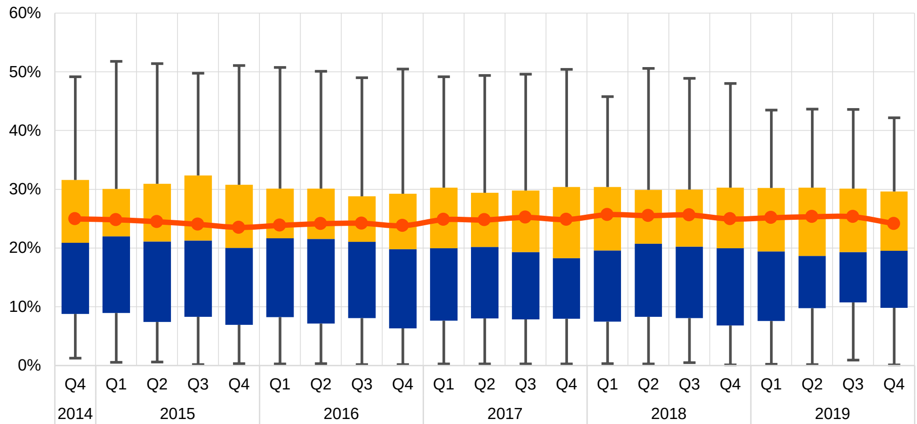
Chart A.1

Distribution of the AE ratios of euro area SIs

a) Not compliant with the minimum LCR requirement (for at least one observed period)



b) Excluding those not compliant with the minimum LCR requirement (for at least one observed period)

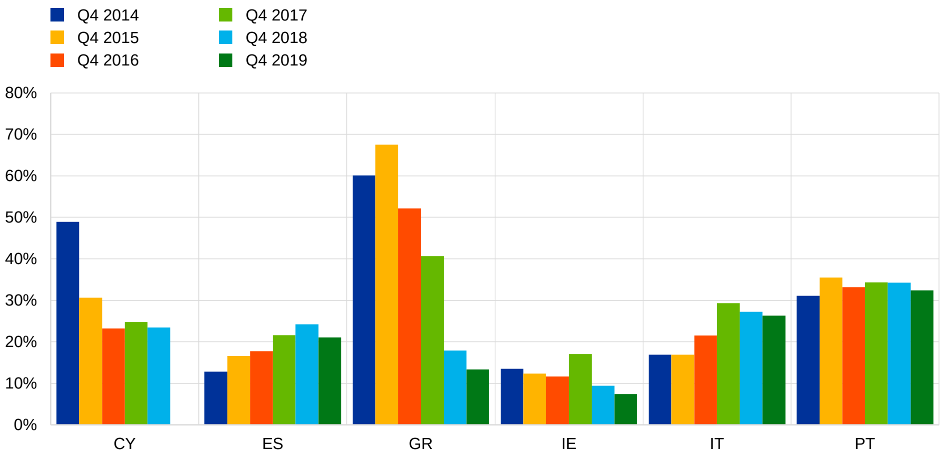


Notes: These charts show the weighted average (in red), the median, the 25th and 75th percentiles (boxes), and the 5th and 95th percentiles (whiskers). The weighted average is computed as the sum of the numerator over the sum of the denominator. Data are based on a dynamic sample of all euro area SIs at each reference period, excluding subsidiaries.

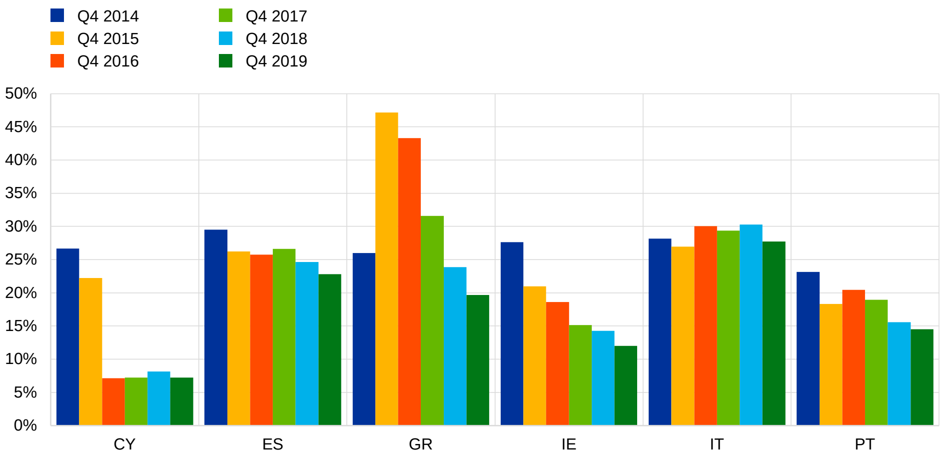
Chart A.2

Central bank funding and AE ratio in countries affected by the sovereign debt crisis – euro area SIs

a) Central bank funding



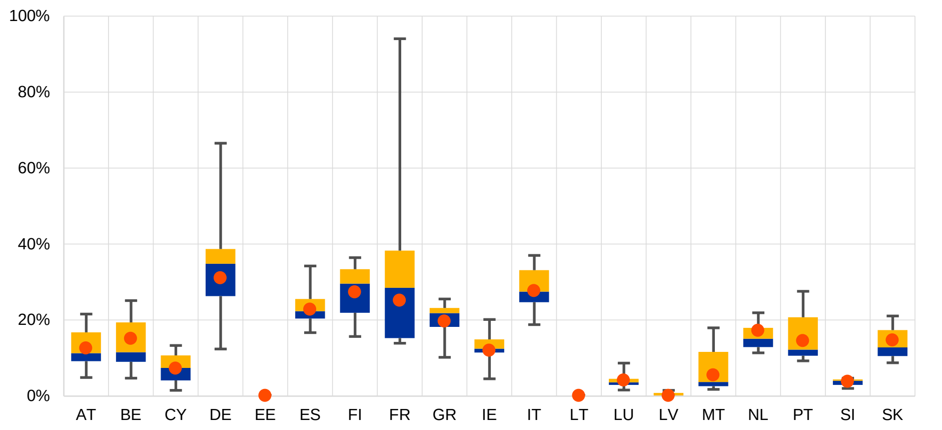
b) AE ratio



Note: Central bank funding and AE ratio in CY, ES, GR, IE, IT, PT. Chart 1.a shows the yearly development of central bank funding (percentage computed with respect to all sources of encumbrance). Chart 1.b shows the yearly development of the AE ratio.

Chart A.3

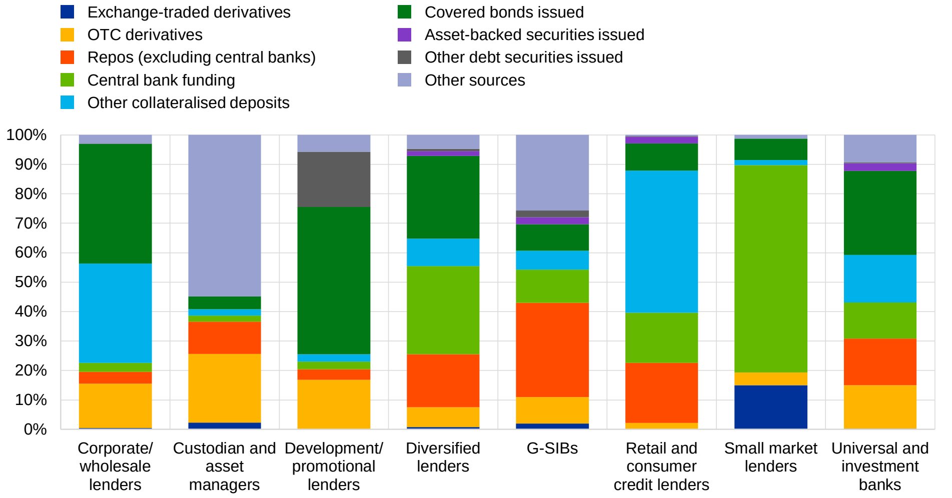
Distribution of the AE ratios of euro area SIs by country in the fourth quarter of 2019



Note: This chart shows the weighted average (in red), the median, the 25th and 75th percentiles (boxes), and the 5th and 95th percentiles (whiskers). The weighted average is computed as the sum of the numerator over the sum of the denominator.

Chart A.4

Distribution of the sources of encumbrance by business model in the fourth quarter of 2019



Note: This chart illustrates the funding sources for which assets have been encumbered by business model. The percentages show the share of each funding source leading to encumbrance, with respect to all liabilities causing encumbrance. Subsidiaries are excluded.

Table A.1

Results of the third econometric set-up (refers to the analysis in Section 4): second stage regressions with time-invariant variables. The first stage results are taken from column 2 of Table 2

	1 AE ratio	2 AE ratio
BE	0.00491 (1.17)	
CY	-0.0157*** (-3.76)	
DE	0.0201*** (2.63)	
EE	-0.0218*** (-3.00)	
ES	0.00852 (1.46)	
FI	0.00414 (0.95)	
FR	0.0120** (2.06)	
GR	-0.0167** (-2.11)	
IE	-0.0000279 (-0.01)	
IT	0.0160** (2.49)	
LU	-0.00413 (-1.19)	
LV	-0.00586 (-1.09)	
MT	-0.00830** (-2.02)	
NL	0.00652* (1.68)	
PT	-0.00120 (-0.25)	
SI	-0.00761* (-1.74)	
Corporate/wholesale lenders		0.0192*** (2.98)
Custodian and asset managers		-0.00272 (-0.46)
Development/promotional lenders		-0.00174 (-0.43)
G-SIBs		0.00928*** (2.74)
Retail and consumer credit lenders		0.00746* (1.76)
Small market lenders		-0.0129** (-2.07)
Universal and investment banks		0.00520 (1.64)
Observations	1,975	1,975
Num. banks	116	116

Note: t-statistics in parentheses; * p<0.1 **p<0.05 ***p<0.01.

Table A.2

Robustness checks relative to the analysis in Section 4

	1 AE_{adj} ratio	2 AE_{adj} ratio	3 CBCC	4 CBCC	5 AE ratio	6 AE ratio	7 AE_{CB} ratio	8 AE_{CB} ratio
NPL ratio	0.260** (2.48)	-0.120 (-0.66)	0.799*** (2.93)	-0.277 (-0.85)	0.541*** (2.84)	-0.145 (-0.78)	0.365* (1.91)	-0.0958 (-0.93)
NIG x NPL ratio		0.462** (2.42)		1.312*** (3.33)		0.837*** (3.55)		0.562*** (2.93)
CBE ratio	0.0818** (2.20)	0.0878** (2.33)	-0.104 (-0.95)	-0.0883 (-0.79)	0.176*** (3.77)	0.186*** (3.82)	0.318*** (5.46)	0.325*** (5.44)
CET1 ratio	-0.0229 (-0.45)	-0.0330 (-0.63)	0.138 (1.17)	0.110 (0.95)	0.0279 (0.44)	0.0102 (0.17)	0.0333 (0.62)	0.0214 (0.43)
Gov. yield	-1.491*** (-4.44)	-1.662*** (-5.12)	4.081*** (4.03)	3.600*** (3.64)	1.230*** (2.82)	0.883** (2.51)	1.690*** (3.91)	1.457*** (3.97)
Size	0.0216 (1.33)	0.0260* (1.74)	0.0660 (1.60)	0.0789* (1.92)	0.0411* (1.80)	0.0493** (2.32)	0.0229* (1.72)	0.0285** (2.19)
NII	-0.00213** (-1.99)	-0.00243** (-2.02)	0.00636 (1.07)	0.00567 (1.06)	0.00600 (1.42)	0.00557 (1.48)	0.00712* (1.80)	0.00683* (1.89)
NFCI	0.00412** (2.60)	0.00470*** (2.67)	-0.0109 (-1.26)	-0.00946 (-1.20)	-0.00836 (-1.37)	-0.00746 (-1.38)	-0.0104* (-1.82)	-0.00981* (-1.88)
ELA					0.446*** (5.20)	0.459*** (5.63)	-0.145** (-2.27)	-0.136** (-2.38)
GACS					0.0537*** (3.62)	0.0543*** (3.25)	0.0245** (1.99)	0.0250* (1.85)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,139	2,139	2,225	2,225	2,225	2,225	2,225	2,225
Num. banks	112	112	117	117	117	117	117	117
R^2	0.242	0.211	0.319	0.330	0.343	0.347	0.502	0.477

Note: t-statistics in parentheses; * p<0.1 **p<0.05 ***p<0.01.

Table A.3

Robustness checks relative to the analysis in Section 4

	1 AE ratio	2 AE_{CB} ratio	3 AE ratio	4 AE ratio	5 AE ratio	6 AE ratio	7 AE_{CB} ratio
L(AE ratio)	0.959*** (85.10)		0.882*** (34.32)	0.906*** (28.95)	0.897*** (28.83)	0.909*** (29.16)	
L(AE_{CB} ratio)		0.962*** (83.60)					0.895*** (34.25)
D(NPL ratio)	0.158** (2.16)	0.116** (2.23)	0.0953* (1.80)	0.109** (2.05)	0.0880 (1.60)	0.128** (2.12)	0.136** (2.45)
D(CBE ratio)	0.0818*** (2.87)	0.247*** (4.30)	0.0837*** (3.90)	0.0847*** (3.81)	0.0884*** (4.13)	0.0888*** (4.02)	0.241*** (4.71)
D(CET1 ratio)	-0.0249 (-1.04)	-0.0106 (-0.52)		-0.207*** (-3.91)			
D(CET1 $ratio^2$)				0.194*** (4.17)			
LR			-0.465*** (-2.60)				
LR^2			1.129* (1.79)				
D(LR)					-0.904*** (-3.85)		
D(LR^2)					2.847*** (2.95)		
Gov. yield	0.217** (2.48)	0.0211 (0.41)	0.430*** (3.24)	0.381*** (2.61)	0.358** (2.43)	0.432*** (2.99)	0.210** (2.26)
Size	0.00196*** (2.97)	0.000746** (2.28)					
NII			0.00317** (2.11)	0.00294** (2.23)	0.00296** (2.10)		
NFCI			-0.00439** (-2.03)	-0.00402** (-2.12)	-0.00411** (-2.04)		
ELA			0.0382 (1.56)	0.0358 (1.37)	0.0545** (2.03)	0.0281 (1.06)	-0.0173 (-0.96)
Time-invariant size						0.00422*** (2.81)	0.00204*** (3.40)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effect	No	No	Yes	Yes	Yes	Yes	Yes
Observations	2,106	2,106	1,934	1,973	1,929	1,975	1,975
Num. banks	117	116	115	116	114	116	115

Note: t-statistics in parentheses; * p<0.1 **p<0.05 ***p<0.01.

Table A.4

Number of banks by country in the early warning indicator sample

Country	Number of banks
Austria	5
Belgium	3
Germany	9
Spain	13
Finland	1
France	7
Greece	4
Ireland	3
Italy	11
Latvia	1
Malta	1
Netherlands	4
Portugal	3
Slovenia	1
Slovakia	1
Total	**67**

Note: Cypriot banks are excluded from the sample as the crisis in these banks started before the beginning of the sample period.

Table A.5

Robustness check relative to the analysis in Section 6: logit model based on indicators selected from the variable importance method and the multicollinearity selection process

R1: cases linked to a systemic crisis event are excluded

Coefficients	Estimate	Standard error	Z-value	Pr(>|z|)	
(Intercept)	-5.691	0.505	-11.273	0.000	****
texas_ratio_2	0.030	0.004	7.689	0.000	****
npl_ratio_2	0.110	0.016	7.052	0.000	****
cbc_ov_2	-0.003	0.002	-1.676	0.094	*
d_ae_2	0.044	0.035	1.257	0.209	
d_texas_ratio_2	0.019	0.009	2.208	0.027	**
roe_2	-0.006	0.005	-1.173	0.241	
d_roe_2	-0.021	0.006	-3.603	0.000	****
ltd_2	0.002	0.002	1.124	0.261	
d_dep_ofc_2	-0.018	0.021	-0.881	0.378	
AIC	**418.46**				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

Table A.6

Robustness check relative to the analysis in Section 6: logit model based on indicators selected from the variable importance method and the multicollinearity selection process

R2: cases linked to an idiosyncratic crisis are excluded

Coefficients	Estimate	Std. error	Z-value	Pr(>|z|)	
(Intercept)	-5.827	0.657	-8.871	0.000	****
texas_ratio_2	0.031	0.005	6.374	0.000	****
npl_ratio_2	0.103	0.017	6.197	0.000	****
cbc_ov_2	-0.003	0.002	-1.207	0.228	
d_ae_2	0.060	0.017	3.630	0.000	****
d_texas_ratio_2	0.003	0.009	0.282	0.778	
roe_2	-0.050	0.013	-3.926	0.000	****
d_roe_2	-0.029	0.014	-2.105	0.035	**
ltd_2	-0.005	0.003	-1.817	0.069	*
d_dep_ofc_2	0.017	0.016	1.114	0.265	
AIC	297.79				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

Table A.7

Robustness check relative to the analysis in Section 6: logit model based on indicators selected from the variable importance method and the multicollinearity selection process

R3: cases linked to state-owned banks are excluded

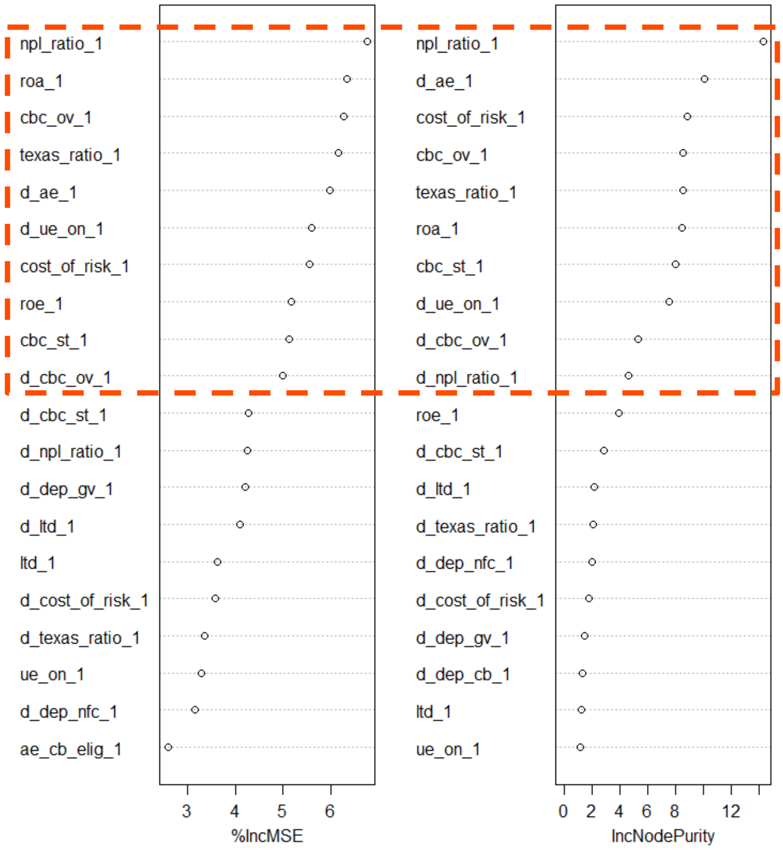
Coefficients	Estimate	Std. error	Z-value	Pr(>|z|)	
(Intercept)	-4.601	0.465	-9.895	0.000	****
texas_ratio_2	0.024	0.004	5.839	0.000	****
npl_ratio_2	0.073	0.013	5.492	0.000	****
cbc_ov_2	-0.001	0.002	-0.409	0.683	
d_ae_2	0.051	0.017	3.002	0.003	***
d_texas_ratio_2	0.136	0.028	4.781	0.000	****
roe_2	-0.022	0.008	-2.852	0.004	***
d_roe_2	0.000	0.006	-0.013	0.990	
ltd_2	-0.001	0.002	-0.297	0.766	
d_dep_ofc_2	0.002	0.017	0.105	0.916	
AIC	369.48				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

Chart A.5

Robustness check relative to the analysis in Section 6: variables selected using the random forest variable importance method

three-month forecast horizon

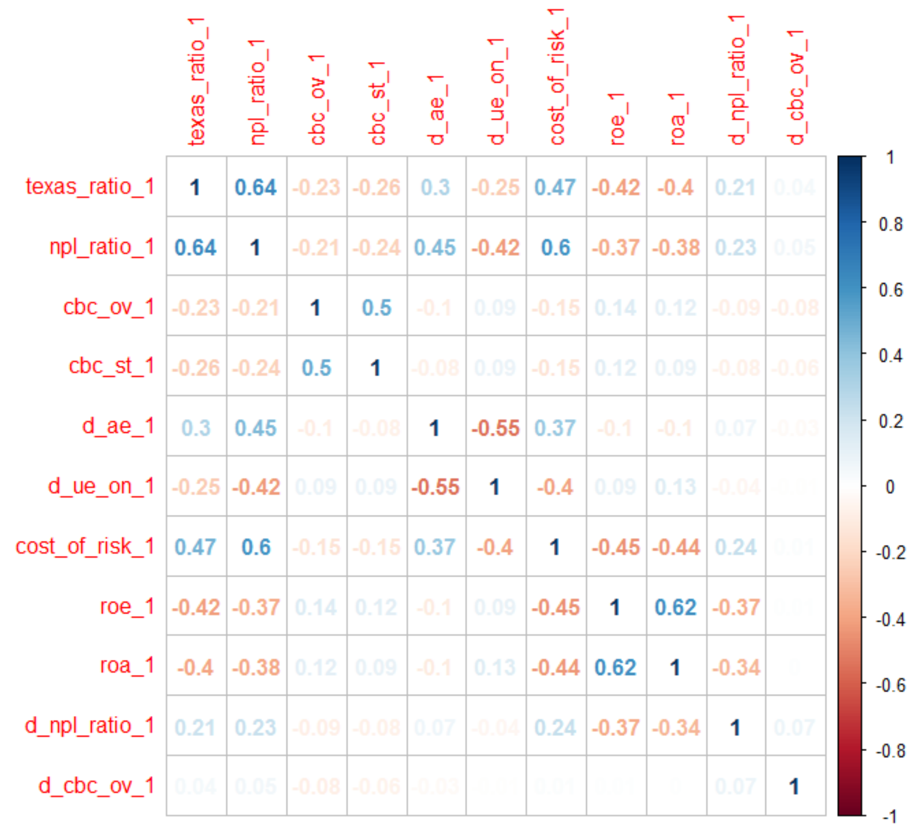


Note: Variable importance is employed to classify crisis periods with respect to non-crisis periods, following a random forest approach. The variables have been ranked according to two different performance measures: mean square error (left-hand column) and node purity (right-hand column). The red box highlights the ten most important variables according to each measure, leading to a set of 11 different variables (most variables in the red box appear in both columns).

Chart A.6

Robustness check relative to the analysis in Section 6: independent variable correlation matrix

Three-month forecast horizon



Note: Correlation coefficients of the 11 variables selected using the random forest importance method. The variables dropped from the analysis because of multicollinearity are: roa_1 (0.62 correlation with roe_1); cbc_st_1 (0.50 correlation with cbc_ov_1); cost_of_risk_2 (-0.60 correlation with npl_1); d_ue_on (-0.55 correlation with d_ae_1).

Table A.8

Robustness check relative to the analysis in Section 6: logit model based on indicators selected from the variable importance method and the multicollinearity selection process

Three-month forecast horizon

Coefficients	Estimate	Std. error	Z-value	Pr(>|z|)	
(Intercept)	-4.219	0.365	-11.560	0.000	****
texas_ratio_1	0.021	0.003	6.276	0.000	****
npl_ratio_1	0.071	0.011	6.170	0.000	****
cbc_ov_1	-0.003	0.002	-1.340	0.180	
d_ae_1	0.051	0.017	3.005	0.003	***
roe_1	-0.027	0.007	-3.924	0.000	****
d_npl_ratio_1	0.074	0.062	1.191	0.234	
d_cbc_ov_1	0.005	0.003	1.696	0.090	*
AIC	447.43				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

Table A.9

Robustness check relative to the analysis in Section 6: logit model based on indicators selected from the variable importance method and the multicollinearity selection process

R1: cases linked to a systemic crisis event are excluded – three-month forecast horizon

Coefficients	Estimate	Std. error	Z-value	Pr(>|z|)	
(Intercept)	-4.829	0.403	-11.987	0.000	****
texas_ratio_1	0.024	0.004	6.699	0.000	****
npl_ratio_1	0.105	0.015	6.974	0.000	****
cbc_ov_1	-0.003	0.002	-1.799	0.072	*
d_ae_1	0.097	0.029	3.361	0.001	****
roe_1	-0.001	0.006	-0.153	0.878	
d_npl_ratio_1	0.223	0.073	3.048	0.002	***
d_cbc_ov_1	-0.002	0.003	-0.514	0.607	
AIC	426.74				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

Table A.10

Robustness check relative to the analysis in Section 6: logit model based on indicators selected from the variable importance method and the multicollinearity selection process

R2: cases linked to an idiosyncratic crisis event are excluded – three-month forecast horizon

Coefficients	Estimate	Std. error	Z-value	Pr(>|z|)	
(Intercept)	-6.393	0.666	-9.606	0.000	****
texas_ratio_1	0.028	0.005	6.019	0.000	****
npl_ratio_1	0.113	0.017	6.595	0.000	****
cbc_ov_1	-0.002	0.002	-0.992	0.321	
d_ae_1	0.096	0.020	4.767	0.000	****
roe_1	-0.041	0.013	-3.038	0.002	***
d_npl_ratio_1	0.127	0.063	1.998	0.046	**
d_cbc_ov_1	0.000	0.004	0.013	0.990	
AIC	273.43				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

Table A.11

Robustness check relative to the analysis in Section 6: logit model based on indicators selected from the variable importance method and the multicollinearity selection process

R3: cases linked to state-owned banks are excluded – three-month forecast horizon

Coefficients	Estimate	Std. error	Z-value	Pr(>|z|)	
(Intercept)	-4.413	0.394	-11.197	0.000	****
texas_ratio_1	0.023	0.004	5.942	0.000	****
npl_ratio_1	0.076	0.013	6.029	0.000	****
cbc_ov_1	-0.002	0.002	-1.201	0.230	
d_ae_1	0.050	0.016	3.083	0.002	***
roe_1	-0.037	0.008	-4.742	0.000	****
d_npl_ratio_1	-0.128	0.078	-1.642	0.101	
d_cbc_ov_1	0.000	0.003	-0.046	0.963	
AIC	406.24				

Note: * p<0.1 **p<0.05 ***p<0.01 ****p<0.001.

Table A.12

Robustness check relative to the analysis in Section 6

Three-month forecast horizon

	Predicted as non-crisis cases	Predicted as crises cases	Signal	Rate
Non-crisis cases	625	75	False alarm	11%
Crisis cases	2	10	Hit Rate	83%

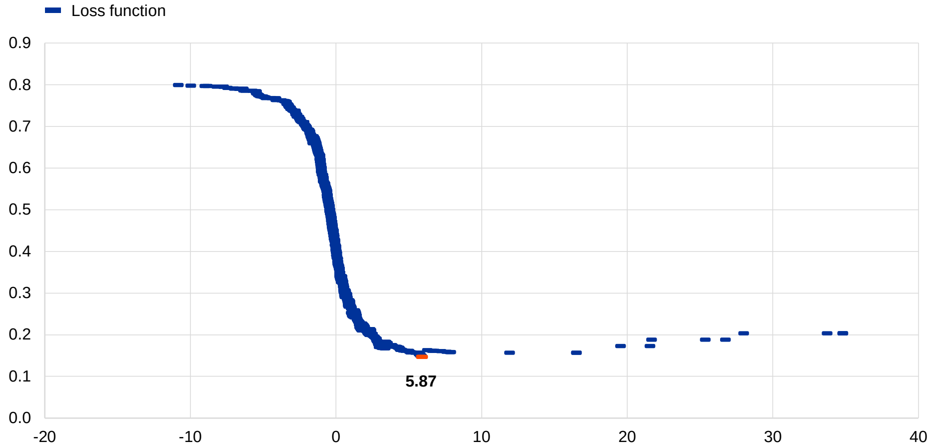
Note: Classification performance of the model evaluated with the original sample (67 SIs from Q4 2014 to Q3 2017), which includes 712 quarterly observations, 12 of which are the starting quarter of a crisis period. The AUROC metric of the logit model is 95%, indicating adequate fit.

Chart A.7

Robustness check relative to the analysis in Section 6: loss function (y-axis) for the change in AE ratio based on different cut-offs (x-axis)

Three-month forecast horizon

(x-axis: cut-off for the quarterly change in asset encumbrance (d_ae) measured in percentage points)



Note: A 5.87% quarterly increase in the AE ratio minimises the loss function that weights type I and type II errors in crisis prediction.

Table A.13

Robustness check relative to the analysis in Section 6: optimal thresholds recognised from the signalling approach

Three-month forecast horizon

Variables	Crisis Threshold	Up/Low	Error
Texas ratio (%)	109,4	Up	0,105
NPL ratio (%)	25,62	Up	0,095
Return on assets (%)	-1,56	Low	0,129
Cost of credit risk (%)	2,05	Up	0,108
Return on equity (%)	-16,52	Low	0,136
Change in AE ratio (p.p.)	5,87	Up	0,146
Change in NPL ratio (p.p.)	1,66	Up	0,153
Change in unencumbered-to-total assets ratio (p.p.)	-7,76	Up	0,142

Note: For eight of the 11 variables selected using the random forest variable importance method, the thresholds that minimise the loss function have been computed. This is a univariate analysis (i.e. each variable is evaluated separately), thus there are no multicollinearity issues. This allows us to show the results for variables that previously were excluded from the logit model. The results for short-term counterbalancing capacity, overall counterbalancing capacity and the change in the overall counterbalancing capacity are omitted as the relevant thresholds are non-informative.

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Pierre Berthonnaud
Autorité de contrôle prudentiel et de résolution, Paris, France; email: pierre.berthonnaud@acpr.banque-france.fr

Enrico Cesati
European Central Bank, Frankfurt am Main, Germany; email: enrico.cesati@ecb.europa.eu

Maria Ludovica Drudi
Banca d'Italia, Rome, Italy; email: marialudovica.drudi@bancaditalia.it

Kirsten Jager
De Nederlandsche Bank, Amsterdam, The Netherlands; email: k.j.jager@dnb.nl

Heinrich Kick
European Central Bank, Frankfurt am Main, Germany; email: heinrich.kick@ecb.europa.eu

Marcello Lanciani
European Central Bank, Frankfurt am Main, Germany; email: marcello.lanciani@ecb.europa.eu

Ludwig Schneider
Deutsche Bundesbank, Frankfurt am Main, Germany; email: ludwig.schneider@bundesbank.de

Claudia Schwarz
European Central Bank, Frankfurt am Main, Germany; email: claudia.schwarz@ecb.europa.eu

Vasileios Siakoulis
Bank of Greece, Athens, Greece; email: vsiakoulis@bankofgreece.gr

Robert Vroege
De Nederlandsche Bank, Amsterdam, The Netherlands; email: a.j.vroege@dnb.nl

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

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