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Asset encumbrance in banks: Is systemic risk affected?

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ABSTRACT

The growing reliance on secured funding by banks has increased the relevance of collateralization and asset encumbrance (*AE*). This paper examines the main determinants of *AE* and verify its effects on banks' systemic risk, which threatens financial stability. Using a novel dataset including hand-collected data on *AE* from banks' Pillar III reports, we perform a panel regression analysis for European listed banks from 2014 to 2019. We find that the *AE* ratio is driven mainly by the bank business model, capitalization and sovereign funding conditions. Our empirical results highlight that it is not the *AE* level per se that influences banks' systemic risk, but rather the change in encumbered assets. Nevertheless, bank capitalization plays a strong moderating role in this relationship. According to our results, supervisors and policy makers should pay specific attention to the combined phenomena involved in the increasing encumbrance in less capitalized banks.

1. Introduction

Against the background of the financial crisis that started in 2007, the structure of European banks' liabilities underwent a significant shift towards secured debt, with a consequent increase in the use of collaterals (International Monetary Fund, 2013; European Banking Authority, 2019). Concerns over sovereign risk in conjunction with declines in the quality of bank assets were among the key catalysts of this development and adversely influenced banks' access to unsecured funding markets (Ahnert et al., 2019; Committee on the Global Financial System, 2011; European Systemic Risk Board, 2013; Houben and Slingenberg, 2013). Besides, the spread of unconventional monetary policies contributed to an increased demand for instruments that could be used as collateral for central bank funding in the euro area (Committee on the Global Financial System, 2013; Rixtel and Gasperini, 2013). Prudential supervision that requires larger buffers of high-quality liquid assets also played a role in determining certain shifts in bank funding patterns towards collateralized debt (Basel Committee on Banking Supervision, 2019).

The increased reliance on secured funding by banks and the move towards collateralization boosted the intensification of asset encumbrance (*AE*, hereafter).

According to the European Banking Authority's definition, an asset is encumbered if it has been pledged or if it is subject to any form of arrangement to secure, collateralize or credit-enhance any on-balance-sheet or off-balance-sheet transaction from which it cannot be freely withdrawn (e.g., to be pledged for funding purposes). Assets that require prior approval before withdrawal or replacement by other assets should also be considered encumbered (European Banking Authority, 2014).

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The highest amount of *AE* is observed in countries with large and established covered bond markets (e.g., the European Nordic countries and Germany), countries with a high share of repo financing (e.g., France), and countries where there has been a more intense use of central bank funding (e.g., Greece and Italy).

Interest in analysing the potential impact of high and rising levels of *AE* on the financial system has grown rapidly among regulators, supervisors, and scholars (Committee on the Global Financial System, 2013; European Banking Authority, 2021).

While the sources and adverse implications of *AE* have already been widely examined from a theoretical point of view, *AE* has been poorly explored empirically thus far because of data limitations (Banal-Estanol et al., 2017; Banal-Estanol et al., 2018; Berthonnaud et al., 2021; Garcia-Appendini et al., 2023). Banks have only been recommended by regulators to disclose data on *AE* in their Pillar III documents since 2014, and only within more recent years have supervisors begun to provide some insights into *AE* dynamics.

Our paper, based on a novel dataset including hand-collected data on *AE,* aims to fill this research gap by verifying the potential effects of *AE* on the stability of financial markets. In particular, we address the following research questions:

RQ1) Which are the bank-specific characteristics that mostly affect the level of bank *AE*?

RQ2) Which effects are produced on systemic risk by a change in the level of bank *AE*?

RQ3) Do bank-specific characteristics moderate the relationship between the change in *AE* and systemic risk?

Banks' systemic risk is evaluated using the *SRISK* index, which was introduced by Brownlees and Engle (2012, 2017) to measure the capital shortfall that a financial institution is expected to experience conditionally on a prolonged market decline. The use of this indicator involves the need to carry out empirical verification on listed banks. Our sample is made up of all European listed banks that provide complete data on *AE* for the years 2014–2019. We also verify whether some relevant bank-specific characteristics play a moderating role in the relationship between *AE* and banks' systemic risk, which is relevant for guiding policy makers and supervisors in the proper monitoring and regulation of credit financial institutions.

The contribution of our study to the literature is manyfold.

First, we improve knowledge of *AE* by providing novel evidence on its main determinants. To this aim, we consider an exhaustive measure of encumbrance that is based on the data disclosed by banks, differentiating from the studies that use partial measures e.g., the amount of outstanding covered bonds issued (as Garcia-Appendini et al., 2023).

Second, we analyse the effect of *AE* on banks' systemic risk, moving forward compared to the studies that focus on the relationship between *AE* and individual bank solvency risk (Banal-Estanol et al., 2017; Banal-Estanol et al., 2018; Berthonnaud et al., 2021; Garcia-Appendini et al., 2023). In the aftermath of the Global Financial Crisis a renewed interest has arisen from academicians, practitioners, and financial regulators on systemic risk (Zhang et al., 2023; De Simone, 2021; Derbali and Hallara, 2016). Since *AE* is particularly alarming in cases of distress and potential for contagion (European Banking Authority, 2019; European Systemic Risk Board, 2013), we investigate its relationship with banks' systemic risk, which is crucial for the stability of the financial system.

Third, we widen the literature by examining the impact of *AE* dynamics. In addition to investigating the effects of high levels of *AE* (Banal-Estanol et al., 2017; Banal-Estanol et al., 2018; Berthonnaud et al., 2021), our analysis aims to verify the impact of a change in these levels over time, providing relevant implications for supervisors and regulators who intend to monitor the trend of *AE* to prevent crises.

In addition, we explore the moderating drivers in the relationship between AE trends and systemic risk, by identifying the bank-specific conditions under which supervisors and regulators should pay close attention to *AE* dynamics, offering new insights into the determinants of financial instability.

Concerning the drivers of *AE*, our main findings show a nonmonotonic relationship between the level of *AE* and bank capitalization. The average marginal effect is negative, but beyond a certain threshold, the relationship changes sign. We also find a positive significant relationship between *AE* and the sovereign risk of the bank's home country.

The results of our empirical investigation on the effects of *AE* show a positive and significant relationship between systemic risk and a change in *AE*. Nevertheless, banks' characteristics, such as the level of capitalization, can modify the sign of this linkage. A growth in *AE* is beneficial to systemic risk if it is accompanied by a high level of regulatory capital. These results indicate the need to manage the *AE* trend while taking into consideration the degree of bank capitalization.

The rest of the paper is structured as follows. Section 2 provides the definition of the core metric for measuring *AE* according to the regulatory approach. Section 3 reviews the literature on *AE* and presents our hypotheses. Section 4 describes our sample and methodology. Results and robustness tests are reported in Section 5. Finally, conclusions and policy implications are described in Section 6.

2. The regulatory approach to asset encumbrance

AE has recently become a much-discussed subject, and policy makers have been actively addressing what they consider to be excessive levels of *AE*. Some jurisdictions have introduced limits on the level of *AE* (Australia, New Zealand) or ceilings on the amount of secured funding or covered bonds (US), while others have incorporated *AE* levels in deposit insurance premiums (Canada). Within the Basel III regulatory framework, the net stable funding ratio (NSFR) heavily penalizes *AE* by requiring substantial amounts of stable funding to finance encumbered assets (Basel Committee on Banking Supervision, 2019). Several studies have proposed establishing further caps on *AE* as a backstop (Helberg and Lindset, 2014; IMF, 2013; Juks, 2012). At the European level, in 2013, the ESRB issued its 'Recommendations on Banks' Funding'. It recognized that beyond a certain level, *AE* becomes self-amplifying and accelerates to the point where secured funding is impossible because of a lack of collateral and, at the same time, unsecured funding is not feasible because of the higher risk premia. However, there is no unique threshold for all financial institutions beyond which *AE* is considered unsustainable. For this reason, the ESRB avoids introducing a specific regulatory limit for banks' *AE*. Instead, it supports the development of guidelines to provide disclosure across the EU based on a harmonized definition of *AE*, enabling market participants to compare financial institutions in a clear and consistent manner. In addition, the ESRB asks intermediaries to carry out internal policies to suitably identify, manage and monitor the risks stemming from collateral management and *AE*. Following the ESRB's recommendations, the EBA issued its 'Implementing Technical Standards on AE Reporting' that evolved into a final discipline in December 2014 (European Banking Authority, 2014; European Commission, 2015). The EBA encourages supervisors to closely oversee the level and evolution of AE and financial institutions to strengthen disclosure on the matter.

In March 2017, the EBA issued regulatory technical standards on the disclosure of encumbered and unencumbered assets. Banks are expected to publish data on *AE* in their Pillar 3 disclosures on at least an annual basis, by filling.in three templates and a box for narrative information.

In the EBA's discipline, a uniform approach has been defined for measuring *AE* through standard metrics across institutions. The core metric is the asset encumbrance ratio (*AER*), which measures the value of the assets that are pledged as collateral and the amount of the collateral received and reused by an institution relative to the bank's total on- and off-balance-sheet assets:

$$AER = \frac{Total\ Encumbered\ Assets + Total\ Collateral\ Received\ and\ Reused}{Total\ Assets + Total\ Collateral\ Received\ Available\ For\ Encumbrance} \quad (1)$$

Another measure of AE, which we call simplified *AER* (*AERs*), is the ratio of encumbered assets to total assets:

$$AERs = \frac{Total\ Encumbered\ Assets}{Total\ Assets} \quad (2)$$

This ratio has been proposed by the Bank of England (2012) and European Systemic Risk Board (2013) to undertake analyses of the UK and European banking sectors, respectively, and captures the proportion of balance sheet assets that have been encumbered. As opposed to the EBA's metric, this measure leaves out off-balance-sheet collateral.

3. Literature review and hypotheses

The increase in the levels of *AE* experienced in Europe in the last decade has captured the attention of scholars, policy makers, and supervisors, who have tried to investigate the drivers of *AER* and the effects generated by high levels or significant variations in the ratio. In Sections 3.1 and 3.2, we depict the main findings of the literature on these topics and formulate our hypotheses.

3.1. The AE drivers

According to Ahnert et al. (2019), banks choose their optimal level of *AE* by balancing a trade-off between the cheaper cost of secured funding on the one hand and the risks caused by potential runs on unsecured debt on the other hand. Several factors may tip the scale, thus affecting the resulting level of banks' *AE*. In some cases, the same driver can even affect the exposure to *AE* in different ways. The link between *AE* and banks' capitalization is a clear example of this ambiguity, as emerges from the theoretical model by Ahnert et al. (2019). On the one hand, sound capitalization could reduce banks' risk of runs by unsecured creditors, thus leading banks to increase their *AE* to cut their cost of funding. On the other hand, less capitalized banks might be required to pay higher risk premia to unsecured creditors and could be compelled to rely on secured funding, which would increase their *AE* (European Banking Authority, 2016; European Banking Authority, 2021). Some econometric specifications show a convex relationship between capitalization and *AE* (Berthonnaud et al., 2021). These considerations lead to the following hypothesis:

H1. : A nonmonotonic relationship exists between bank capitalization and the level of *AE*.

Unsecured funding might also be more expensive, or not available at all, for less profitable banks, which would force them to switch to secured borrowing and boost *AE*. Thus, banks' profitability is another possible driving factor of *AE*. Based on data from December 2015, the European Banking Authority (2016) observed a negative relationship. Consequently, our paper tests the following hypothesis:

H2. : A negative relationship exists between the level of bank profitability and the level of *AE*.

Furthermore, banks with a higher level of credit risk are subject to fund rationing by unsecured investors, who demand higher risk premia (Di Filippo et al., 2020). Nevertheless, riskier institutions are still able to refinance in the secured market by pledging collateral (Hoerova and Monnet, 2016), as secured borrowing is less (or is not) information sensitive (Dang et al., 2012; Gorton and Ordoñez, 2014).

Therefore, banks with higher credit risk replace unsecured with secured borrowing, and the level of *AE* rises. In its investigation of the drivers of *AE*, the European Central Bank (ECB) highlights that the appetite for *AE* is more developed for banks with higher NPL ratios (Berthonnaud et al., 2021). A higher portion of deteriorated assets in banks' balance sheets worsens the structural subordination of unsecured creditors who, in turn, avoid the rollover of their loans, forcing banks to switch to covered funding. Based on previous literature, the following hypothesis is posited:

H3. : A negative relationship exists between the level of quality in bank credit assets and the level of *AE*.

A special case of asset-side deterioration originates from the sovereign–bank nexus (Berthonnaud et al., 2021). As suggested by Dell'Ariccia et al. (2018) and Guerrero et al. (2020), the financial health of sovereigns may impact banks through three channels: the exposure of banks to sovereign debt, government guarantees to banks, and banks' exposure to the domestic economy. Therefore, a worsening of sovereign financial conditions may negatively affect banks' ability to attract unsecured borrowers, leading to an increase in their *AE*. Moreover, government bonds are widely used as collateral for secured funding (Berthonnaud et al., 2021). An increase in government yields produces a depreciation in government debt securities that have been collateralized by banks, which requires additional collateral to be posted. This linkage strengthens the relationship between sovereign yields and banks' *AE*. Thus, drawing on these considerations, our paper verifies the following hypothesis:

H4. : Domestic sovereign bond yields are positively related to the level of *AE* due to the sovereign–bank nexus.

In testing these hypotheses, we also control for banks' size, business model, and geographical area in which they are settled. Indeed, as suggested by Banal-Estanol et al. (2017) and Banal-Estanol et al. (2018), *AE* cannot be handled uniformly across banks, whose exposure to encumbrance depends first on their size. In addition, other authors show that *AE* evolves differently across bank business models and European countries (Berthonnaud et al., 2021).

3.2. The AE effects

The literature on *AE* has focused on identifying its adverse implications, at both the macro and micro levels.

Concerning macro effects, they mainly relate to the credit supply channel. The higher a bank's reliance on secured funding, the greater the likelihood that it will prefer investing in eligible assets for encumbrance, i.e., top-rated government bonds and commercial and residential mortgages, instead of granting loans to small and medium-sized enterprises (European Systemic Risk Board, 2013). Therefore, an increase in secured funding may lead to reduced credit supply to ineligible/less eligible sectors (Singh, 2011).

Besides, *AE* may generate a variety of negative consequences for both the financial sector and financial institutions, at a micro level. First, excessive *AE* may negatively impact the stability of banks' funding profile (Bank of England, 2019). As banks encumber a higher proportion of their available assets in normal times, they will be less able to secure additional assets should a tension occur (Mayer et al., 2018; Migliasso, 2018). This makes banks less resilient to distress, which may cause investors to charge higher spreads or react faster to stress signals. As the market's confidence in banks diminishes, their creditors and other counterparties may seek to apply larger haircuts on collateral and make margin calls. Therefore, high levels of *AE* may give rise to an adverse spiral, leading to yet higher encumbrance and diminishing banks' ability to generate additional liquidity even further ('contingent encumbrance').

An additional way in which *AE* can negatively influence banks' funding stability is the structural subordination of unsecured creditors (Juks, 2012; Le Leslé, 2012; Houben and Slingenberg, 2013; IMF, 2013; International Capital Market Association, 2014; Garcia-Appendini et al., 2023). Encumbered assets cannot be freely transferred or realized; they are thus not available to unsecured creditors in the event of a bank liquidity crisis. Since secured creditors have first rights on collateralized assets, *AE* makes the claims of banks' unsecured bondholders and depositors riskier (Matta and Perotti, 2015; Ahnert et al., 2019). Focusing on the European covered bond market, Garcia-Appendini et al. (2023) find that *AE* significantly affects the risk associated with unsecured debt by effectively reducing the seniority of these claims. Moreover, they show that high encumbrance leads to greater funding fragility if banks do not have enough liquidity buffers to service early withdrawals.

The extent to which risk-shifting penalizes unsecured creditors depends on their capacity to price that risk. Consequently, an unexpected growth in the level of *AE* pose higher concerns for existing unsecured creditors if they do not have an opportunity to price such encumbrance changes (European Systemic Risk Board, 2013). Ahnert et al. (2019) developed a theoretical model based on the trade-off between cheap secured funding and fragility, concluding that high *AE* levels may lead to a crisis even for banks that are adequately capitalized. Furthermore, high *AE* can reduce the variety of counterparties willing to invest in bank debt, potentially overconcentrating the market (Juks, 2012). Since banks have limits on their exposures to a single counterparty, this could further restrict their funding management (Erhardt et al., 2017). Another risk arises from the fact that it is more difficult to manage and supervise banks with a high level of encumbrance because of the scarcity of options available for funding activities should shocks occur (Garcia-Appendini et al., 2023).

Examining the impact of European listed banks' securitisation activity and covered bond issuance on their systemic risk, Arif (2020) concludes that smaller banks have limited assets and the encumbrance of some assets might arise some concerns, since their systemic risk increases after the issuance of covered bonds. On the contrary, bigger banks have a larger number of assets and are less prone to the adverse effects of *AE*. In a crisis, the large stock of unencumbered assets can be used to meet the liquidity and funding needs.

While most of the extant literature has focused on the consequences of high *AE* levels, our study aims to verify the impact of *AE* changes on systemic risk. The urgency of effective monitoring and regulation of AE dynamics is underlined by the results of Berthonnaud et al. (2021), which highlight how changes in *AE* can contribute to the accuracy of a multivariate early warning model for predicting bank crises. In addition, European Banking Authority (2023) recommend supervisors to pay close attention to abrupt changes in encumbrance ratios, which could be early warning signs for liquidity and funding risk. Thus, we test the following hypothesis:

H5. : A positive relationship exists between a change in *AE* and systemic risk.

In their analyses on the relationship between European banks' *AE* ratios and CDS spreads, Banal-Estanol et al. (2017) and Banal-Estanol et al. (2018) show that certain bank-level variables play a moderating role in this relationship. For banks that have high exposures to the central bank, have a high leverage ratio, and/or are based in Southern Europe, *AE* may lead to a greater increase in risk. On the other hand, banks with high levels of loan loss provisions or based in Nordic countries benefit from increased levels of *AE*. These results suggest that *AE* cannot be treated uniformly across banks and that regulators need to be prudent when assessing the effects of *AE*. Consequently, the following hypothesis is verified:

H6. : Bank-specific features moderate the relationship between the change in bank *AE* and systemic risk.

We add the level and the change in bank *AE* to the other variables traditionally studied by the literature as the main sources of systemic risk. In particular, banks' size is the most frequently discussed variable in this field (Laeven et al., 2016; Bostandzic and Weiß, 2018). Larger banks are often more complex, more interwoven, less replaceable, and generate higher losses in case of a default than smaller banks.

Overall, the empirical literature tends to find that higher capital levels increase bank soundness. In this respect, higher quality (i.e., core) capital is found to be particularly helpful during crisis periods (Berger and Bouwman, 2011; Brunnermeier et al., 2012; Beltratti and Stulz, 2012; Laeven et al., 2016). Nevertheless, if banks' funding structure is oriented towards short-term debt, even well-capitalized banks can show high systemic risk (Bostandzic and Weiß, 2018) since dependence on short-term funding exposes them to liquidity risks (Brunnermeier and Pedersen, 2009) and lower performance (Fahlenbrach et al., 2012).

Another potential source of systemic risk is banks' business model. As Brunnermeier et al. (2012) and DeYoung and Torna (2013) show, banks that are more engaged in non-core banking activities (such as investment banking) are subject to higher systemic risk.

The quality of banks' loan portfolios is also relevant. Low quality assets exposes banks to high credit contagion and might result in an increase in banks' likelihood of becoming insolvent (Bartram et al., 2007). Likewise, the overall risk profile of banks' assets contributes to banks' systemic risk (Kishore, 2018).

Furthermore, Bologna (2018) highlights that increasing maturity mismatch exposes banks to high funding risk related to the need to roll over short-term liabilities, which may have the potential to threaten both financial institution and financial system stability. Consequently, excessive maturity transformation is undesirable from a financial stability perspective (Hellwig, 2008) since structural funding weaknesses are a key driver of banks' failures (Vasquez and Federico, 2012; IMF, 2013; Bologna, 2015).

According to the "bad management" hypothesis (Berger and De Young, 1997; Williams, 2004), banks operating with low levels of efficiency have higher costs largely due to inadequate risk monitoring and inefficient control of operating expenses. Declines in cost efficiency temporally precede increases in banks' risk due to credit, operational, market and reputational problems (Fiordelisi et al., 2010), which can represent a further channel of systemic risk.

Finally, the literature shows that banks that are more profitable may be in better positions to reduce risk (Berger et al., 2020), negatively impacting systemic risk.

4. Sample and methodology

4.1. Sample

Since the main aim of our study is to verify the relationship between banks' AE and systemic risk, our sample is made up of institutions that, given their presence in international financial markets, are more likely to create risks to financial stability, bringing negative externalities into the system and contributing to market distortions. Our initial sample then included all the European banks that were listed in 2019.

The EBA guidelines on AE disclosure are not mandatory, and for this reason, they are not applied by all European banks. Thus, the final sample includes the listed banks for which AE data are available, resulting in 53 banks from 17 countries (Table A.1). In most cases, the total assets of the sampled banks are more than half of the total banking assets of their home country. Overall, our sample is highly representative of the geographical areas considered in the empirical specifications and at EU level (Table A.2). The statistics of the variables involved in the analysis provide a more in-depth description of the financial institutions included in our sample, as well as of the regions our data refer (Tables A.3 and A.4).

The banks headquartered in Nordic countries (Denmark, Finland, and Sweden) and GIIPS (Greece, Ireland, Italy, Portugal, and Spain) exhibit the highest average AER (around 28% and 26%, respectively). On the other hand, in Core countries (Germany, France, Belgium, Netherlands, and Austria) the average AER is less than 20%, while in Peripheral countries (Lithuania, Malta, Poland, and Hungary) it is around 8%.

The supervisory data reported by the EBA confirm this evidence. In Denmark, Finland, and Sweden high encumbrance ratios are mostly explained by an extensive use of covered bond funding. In Greece and Italy, central bank funding is the main source of *AE*. Thus, the level of AER depends on the type of funding sources that are used by banks at country level. In addition, observing individual AER data material differences across banks emerge. The dispersion in the encumbrance levels and dynamics across banks makes it necessary to identify the bank-specific characteristics that mostly affect bank *AE*, as well as to understand whether bank-specific features moderate the relationship between *AE* and systemic risk.

Regarding the other variables involved in our analysis, in all the analysed geographical areas the traditional bank business model is predominant, as shown by the average net interest income to total income ratio that is above 50%. The average profitability of bank assets (ROA) is around 2%, except for the banks headquartered in the peripheral countries that reach 4%. The quality of assets of the banks operating in GIIPS and peripheral countries is lower than banks in other regions, as shown by the average NPLs ratio (16.7% and 15.7%, respectively). Coherently, the banks of those geographical areas are also characterised by a higher level of capitalisation, measured as Tier 1 capital to total assets (6.8% and 8.8%, respectively, compared to around 5% for the other regions). Unsurprisingly, banks of peripheral countries are smaller than those in the other regions considered. Equally expected is the value of the sovereign yields that are higher in GIIPS and peripheral countries.

The rest of the section is structured as follows. The sub-Section 4.2 explains the methodology applied for verifying the drivers of *AE*, while the sub-Section 4.3 shows the methods applied for testing the effects of *AE* on systemic risk.

4.2. Methodology for identification of AE drivers

To answer our first research question and test H1, H2, H3, and H4 (see Section 3.1), we present the *AE* variable and the bank-specific characteristics that might affect it.

4.2.1. Dependent variable

Since a database providing data on *AE* is not publicly available, the data were hand-collected from the risk disclosures of the banks included in our sample using the information presented in Templates A and B of Pillar III Disclosure reports at the end of 2014–2019. These data are used for calculating both *AER*, according to EBA's definition, and *AERs*, which is considered by the Bank of England and ESRB (see Section 2).

4.2.2. Explanatory variables

We consider as regressors different indicators capturing the level of bank capitalization (proxied by leverage, measured as Tier 1 capital to total assets), bank profitability (proxied by ROA), bank asset quality (proxied by nonperforming loans to total assets), and exposure to sovereign debt performance (measured by the average monthly yields of ten-year domestic government bonds). Since Ahnert et al. (2019) show a nonmonotonic relationship between bank capitalization and AE, we also include a squared transformation of leverage. In addition, we control for banks' size (proxied by the logarithm of total assets), banks' business models (proxied by the weight of net interest income in total income), and the geographical area in which the banks are headquartered.

To avoid reverse causality issues, in the econometric analysis, all time varying explanatory variables are l*agged by one year with respect to the dependent variable.*[1]

The variables used in the analysis are listed in Table 1.

4.2.3. Regression models

To analyse the drivers of *AER*, we lead a panel data regression, taking years as fixed effects and checking banks both as fixed (using the within estimator of parameters) or random effects. Comparing the two alternatives by the Hausman test leads us in all cases to accept the null hypothesis of consistency of both specifications. Therefore, we report only the results from the random effects model in what follows.[2]

The reference model uses the following specification:

$$AER_{i,t} = \alpha' BANK_{i,t-1} + \beta' AREA_i + \gamma Yield_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t} \tag{3}$$

where *i* and *t* denote the bank and the year, respectively; *BANK* denotes a vector related to bank-specific characteristics of the bank at *t*-1; *AREA* indicates a set of time-invariant dummy variables related to the geographical area in which the bank is located; *Yield* is the monthly yield of the 10-year government bond at *t*-1 related to the country where the bank is headquartered; μ_i stands for bank effects; λ_t refers to year fixed effects; and $\varepsilon_{i,t}$ includes idiosyncratic error terms.

When meaningful, and when a variable's unconditional distribution is not highly skewed, we check it in the original scale and in log, retaining the best-fitting one; for highly skewed variables, we consider only their log. Finally, to reduce the collinearity between leverage (taken in log) and its square, we inserted the two covariates in the model by first de-meaning the log-leverage.

4.3. Methodology for identification of AE effects on banks' systemic risk

We develop a second model for checking H5 and H6. We then examine the relationship between a change in the level of bank *AE* and systemic risk, also verifying whether some relevant bank characteristics have a moderating role in this relation.

4.3.1. Dependent variable

The dependent variable has to evaluate the marginal contribution of a single financial institution to global systemic risk. Brownlees and Engle (2012) introduced the *SRISK* index, which measures the capital shortfall that a financial firm is expected to experience conditional on a prolonged market decline. It is used to construct rankings of systemically risky institutions: firms with the highest *SRISK* are the largest contributors to the undercapitalization of the financial system in times of distress. The sum of *SRISK* across all financial institutions is used as a measure of overall systemic risk in the financial system. *SRISK* merges market and balance-sheet information to provide useful insights for monitoring the financial system and, retrospectively, to capture several early signs of crisis. *SRISK* not only depends on equity volatility and correlation, as most market-based systemic risk indices do, but also explicitly considers the size and the degree of leverage of a financial firm (Coleman et al., 2017). Furthermore, *SRISK* considers joint dependence among firms, so it can detect if a small number of large financial institutions pose systemic threats to the entire system (Benoit et al., 2013).

[1] This should entirely avoid endogeneity: reverse causality (in this work the main potential source) is managed as indicated; there should not be omitted variables because we include all those potentially relevant in light of the literature; errors in variables should be minimal.

[2] In addition to being more efficient than fixed effect models, random effect specifications have the advantage of providing coefficient estimates for time-constant dummy variables such as the country area.

Table 1
Variables used to model the drivers of *AE*.

Variable name	Definition	Source	Group
AER	(Total Encumbered Assets + Total Collateral Received and Reused) / (Total Assets + Total Collateral Received Available for Encumbrance)	Hand-collected by Pillar III documents	Dependent variable
AERs	Total Encumbered Assets / Total Assets	Hand-collected by Pillar III documents	Dependent variable
Leverage	Tier 1 Capital/Total Assets	S&P's Capital IQ database and BankScope	BANK
ROA	Total Income/Total Assets		
NPL ratio	NPLs/Gross loans		
Size	Log(Total Assets)		
Business model	Net Interest Income/Total Income		
GIIPS	Geographical Area	Bloomberg	AREA
Nordic			
Peripheral			
Core (reference)			
Sovereign yield	Monthly yield of 10-year government bond	ECB Statistical Datawarehouse	YIELD

The fact that *SRISK* relies only on publicly available information points to a limited universality of the measure (Masciantonio and Zaghini, 2017) since it can be applied only to publicly listed financial institutions. On the other hand, it is relatively inexpensive to implement. In addition, the capital shortfall is estimated based on the market value of equity instead of its book value, making *SRISK* able to encompass the overall degree of risk aversion towards an institution, to capture changes in market conditions faster than typical accounting measures and to be updated more frequently than regulatory stress tests (Brownlees and Engle, 2017). Finally, *SRISK* has proven to be a good predictor of emerging systemic risk in different geographical contexts (Derbali et al., 2015; Zhang et al., 2015; Grinderslev and Kristiansen, 2016; Brownlees and Engle, 2017; Lin et al., 2018).

When we compare the predictive power of *SRISK* with that of other systemic risk measures (such as the CoVaR by Adrian and Brunnermeier, 2011, 2016; CATFIN by Allen et al., 2012; the Systemic Expected Shortfall by Acharya et al., 2010, 2017), *SRISK* turns out to have better performance (Zhang et al., 2015; Grinderslev and Kristiansen, 2016). Moreover, the measure is able to provide an early warning signal of a decline in industrial production and an increase in the unemployment rate (Masciantonio and Zaghini, 2017).

Following the VLAB documentation,[3] which we take as reference, we compute *SRISK* as:

$$SRISK_{i,t} = k \cdot Debt_{i,t} - (1-k) \cdot \left(1 - LRMES_{i,t}\right) \cdot MV_{i,t} \tag{4}$$

where i is the bank and t is the year; $Debt_{i,t}$ stands for the total debt and $MV_{i,t}$ for the market value of the equity; $k = 0.055$ for Europe (0.08 for the rest of the world); and $LRMES_{i,t}$ is the long-run marginal expected shortfall, calculated as:

$$LRMES_{i,t} = 1 - (1-d)^{\beta_{i,t}}$$

with $d = 0.4$ and $\beta_{i,t}$ the dynamic conditional beta versus the reference stock index. In turn, we evaluate *Beta* as $\beta_{i,t} = \rho_{i,t}\frac{\sigma_{i,t}}{\sigma_t}$, where σ_t and $\sigma_{i,t}$are the return volatilities at time t of the stock index and the ith bank, respectively, and $\rho_{i,t}$ is the correlation between the two at time t. Following Brownlees and Engle (2016), we use the GJR-GARCH model (Glosten et al., 1993) to estimate σ_t and $\sigma_{i,t}$ and the standard dynamic conditional correlation (DCC) model (Engle, 2002) to estimate $\rho_{i,t}$. Since our analysis is focused on the European listed banks, we consider the STOXX European 600 as the reference stock market index, since it covers about 90% of the free-float market capitalization of the developed European equity market. Our dataset includes daily data about stock market prices and market capitalizations and quarterly data on book values of assets and equity, all collected from Bloomberg.

To estimate the effect of the covariates on the proportion of capital increase (rather than on the absolute increase) that would be needed in a crisis, we use *NSRISK* as the dependent variable,

$$NSRISK_{i,t} = k \cdot \frac{Debt_{i,t}}{MV_{i,t}} - (1-k) \cdot \left(1 - LRMES_{i,t}\right) \tag{5}$$

i.e., the *SRISK* in Eq. (4) normalized by bank market capitalization (Berger et al., 2020). *SRISK* is used instead as a robustness check.

4.3.2. Explanatory variables

Since *SRISK* measures the amount of *new* capital that the government would need to provide to bail out a bank in case of a crisis, we are interested in investigating the impact generated on that variable by the yearly change in the *AER* (*ΔAER*) (Berthonnaud et al., 2021).

In investigating the relationship between banks' systemic risk and *ΔAER*, we control for idiosyncratic features and country-specific factors. Bank-specific characteristics include variables that originate from the major channels through which financial institutions can become systemically relevant and determine systemic risk: size (proxied by the natural logarithm of total assets), capital adequacy (proxied by Tier 1 capital over risk-weighted assets), funding structure (proxied by total current debt over total debt), business model (proxied by net interest income to total income and gross loans to total assets), asset quality (proxied by provisions to loans and risk-weighted assets to total assets), maturity mismatch (gross loans to total deposits), efficiency (proxied by total operating expenses/total income), economic performance (proxied by total income/total assets), and the level of *AER*.

In addition to analysing the individual contribution of bank-level features to systemic risk, we verify whether these variables play a moderating role in the relationship between banks' systemic risk and *ΔAER*. In this analysis, we follow the findings of Banal-Estanol et al. (2017) and Banal-Estanol et al. (2018), which confirm that the effects of a high level of *AE* are sometimes more beneficial to bank risks and sometimes more harmful if *AE* is associated with some bank-specific characteristics.

In addition, country-specific elements may influence banks' systemic risk. We thus distinguish between the groups of GIIPS countries, Nordic countries, Core countries, and Peripheral countries.

In our robustness checks we include the GDP per capita annual growth and sovereign bond yield spreads (both lagged) as additional controls, based on the significance of these macroeconomic variables in explaining systemic risk according to previous studies (Demirguc-Kunt and Huizinga, 2010; Black et al., 2013).

The variables used in our analysis are listed in Table 2.

4.3.3. Regression models

To investigate how the degree of banks' systemic risk is associated with AER and other covariates, we use panel data regression,

[3] https://vlab.stern.nyu.edu/help/risk_summary?model=GMES

Table 2
Variables used to model the effects of *AE* on banks' systemic risk.

Variable name	Description	Source	Group
SRISK	Eq. (4)	Bloomberg	Dependent variable
NSRISK	Normalized SRISK = SRISK / Market Capitalization	Bloomberg	Dependent variable
ΔAER	Annual Change in Asset Encumbrance Ratio	Hand-collected by Pillar III documents	Variable of main interest
Size	Log (Total Assets)	S&P's Capital IQ database and BankScope	BANK
Tier 1 ratio	Tier 1 Capital/Risk-Weighted Assets		
Debt maturity	Total Current Debt/Total Debt		
Business model	Net Interest Income/Total Income		
ROA	Total Income/Total Assets		
Asset quality	Provisions to loans		
RWA density	Risk Weighted Assets/Total Assets		
Cost income	Total Operating Expenses/Total Income		
Loans to deposits	Gross Loans/Total Deposits		
AER	Level of Asset Encumbrance Ratio	Hand-collected by Pillar III documents	
Sovereign yield bond spread	The spread between 10-year government bond yields of European countries against comparable German bond yields	ECB Statistical Datawarehouse	MACROECONOMIC
ΔGDP per capita	Annual Change in Gross Domestic Product	Eurostat	
GIIPS	Geographical area	Bloomberg	AREA
Nordic			
Peripheral			
Core (reference)			

taking years as fixed effects and checking companies both as fixed (using the within estimator of parameters) or random effects. Like the analysis on the *AER* drivers (Section 4.2), comparing the two alternatives by means of the Hausman test leads us in all cases to accept the null hypothesis of consistency of both specifications. We thus report only the results from the random effects specification.

The reference model is specified as:

$$\ln\left(NSRISK_{i,t}+0.7\right)=\alpha\Delta AER_{i,t-1}+\beta' BANK_{i,t-1}+\gamma' AREA_i+\mu_i+\lambda_t+\varepsilon_{i,t} \tag{6}$$

where *ΔAER* is the yearly change in *AER* between t-2 and t-1; *BANK* denotes a vector related to bank-specific features at t-1, including the level of *AER*; and the other elements are as in Section 4.2.3. The unusual structure of the dependent variable is related to the characteristics of the distribution of *NSRISK*, which is highly right skewed (motivating the log) but with some negative values (requiring the addition of the 0.7 constant) .[4]

Using the pairwise Spearman ρ_S and Pearson ρ_P correlations, we find that some explanatory variables are highly correlated (outside -/+ 0.65): we never include both members of such pairs in the estimated models but, at most, only the best-fitting one.

Regarding the covariates, we investigate two categories of specifications: one without interactions, according to Eq. (6), and another where the role of Δ*AER* is possibly moderated by one or more of the bank characteristics collected in the vector *BANK*, namely:

$$\ln\left(NSRISK_{i,t}+0.7\right)=\alpha\Delta AER_{i,t-1}+\beta' BANK_{i,t-1}+\gamma' AREA_i+\delta'\Delta AER_{i,t-1}\cdot BANK_{i,t-1}+\mu_i+\lambda_t+\varepsilon_{i,t} \tag{7}$$

Considering that the number of observations is small in comparison with the number of variables, we make the model selection by removing from (7) any interactions that are insignificant (at the 5% significance level). When meaningful, we check each variable in the original scale and in log, retaining the best-fitting one.

5. Main results

5.1. AE drivers

The results about the drivers of *AER* and *AERs* (Section 4.2) are shown in Table 3. It emerges that the level of bank capitalization (in log) has a significantly nonmonotonic impact on encumbrance. When we focus on *AER*, its marginal effect (ME, i.e., the first derivative of the dependent variable of interest according to the model) is:

$$ME=\beta_1-2\beta_2 m+2\beta_2 x=\,-1.011-0.327x \tag{8}$$

where $x=\log(\text{Tier 1/Total Assets})$, $m=-2.769$ is its average, and $\beta_1=-0.107$ and $\beta_2=-0.163$ are the coefficients of $x-m$ and $(x–m)^2$, respectively. Accordingly, the ME is positive only when:

[4] For the same reason, in the robustness check presented in Section 5 where SRISK is modelled without the normalization by bank market capitalization, Eqs. (6) and (7) are still used but replacing the dependent variable with $\ln\left(SRISK_{i,t}+3,500\right)$.

Table 3
Models for the drivers of *AER* and *AER*s.

	AER	AERs
	(1)	(2)
log(leverage) - mean (log(leverage))	-0.107 * *	-0.099 *
	(0.040)	(0.040)
(log(leverage) - mean(log(leverage)))^2	-0.163 * *	-0.155 * *
	(0.052)	(0.053)
ROA	-1.663	-1.938
	(1.233)	(1.241)
log(NPL ratio)	0.011	0.013
	(0.014)	(0.014)
Sovereign yield	0.018 * **	0.018 * **
	(0.005)	(0.005)
Size	0.006	-0.005
	(0.010)	(0.010)
Business model	-0.012 * *	-0.011 *
	(0.004)	(0.004)
GIIPS	0.010	0.041
	(0.036)	(0.035)
Nordic	0.037	0.070
	(0.049)	(0.048)
Peripheral	-0.093	-0.075
	(0.050)	(0.050)
Year 2015	0.021	0.021
	(0.014)	(0.014)
Year 2016	0.045 * *	0.043 * *
	(0.015)	(0.015)
Year 2017	0.034 *	0.030 *
	(0.015)	(0.015)
Year 2018	0.021	0.022
	(0.016)	(0.017)
Constant	0.199	0.294 *
	(0.133)	(0.131)
R2	0.308	0.294
Adjusted R2	0.261	0.246
F Statistic	86.807 * **	80.488 * **

Note: Panel regression analysis of AER and AER simplified as a function of some potential drivers (see Eq. (3) and following text). Year (denoted as λ_t in Eq. (3)) and Geographical Area are fixed effects; Banks (denoted as μ_i in Eq. (3)) are random effects. Standard errors in parentheses. Symbols are as follows (p denotes the p value): *p < 0.05; * *p < 0.01; * **p < 0.001.

$$x < m - \frac{\beta_1}{2\beta_2} = -3.095$$

which occurs in 16% of cases (45 out of 284). The average marginal effect is − 0.107, indicating that an increase in capitalization tends generally to diminish the level of *AER*. Nevertheless, the relationship is significantly nonmonotonic, confirming H1.

On the other hand, we do not find a significant relationship between the level of *AER* and banks' profitability or credit deterioration. Specifically, banks' profitability is not able to significantly affect *AER*, in contrast to the empirical evidence shown by the European Banking Authority (2016). H2 is thus rejected. In addition, the credit standing of banks' assets does not seem to have any effect on AE. Thus, we do not confirm the idea (Berthonnaud et al., 2021) that a wide presence of nonperforming assets in banks' balance sheets makes unsecured investors perceive an exacerbation of their structural subordination, leading them not to roll over their investments and forcing banks to switch to covered funding. H3 is thus contradicted. Instead, we find a positive significant relationship between *AE* and sovereign risk in the bank's home jurisdiction, proxied by sovereign yields. The analysis thus confirms H4.

Concerning control variables, our results support that banks' *AE* is influenced by their business model, as shown by the negative significant relationship between *AER* (and *AERs*) and the share of net interest income on total income. Banks that are more oriented towards net interest margin show a lower level of *AE*, as their funding pattern is based mainly on retail deposits. Conversely, banks with large investment banking operations tend to have higher *AE* levels since they fund their trading assets in short-term repo markets (Committee on the Global Financial System, 2013).

5.2. AE effects on banks' systemic risk

The results of our analysis on systemic risk are summarized in Table 4.

The coefficient for the level of *AER* is not significant. Our findings do not demonstrate the existence of a relationship between the degree of *AE* and systemic risk. Instead, we observe a significantly positive effect of the *AE* variation (ΔAER) on the response variable. The empirical evidence points out that it is not the *AER* level per se that influences banks' systemic risk but rather its yearly change. Nevertheless, because of the interaction, we find that the effect of ΔAER depends on the level of bank capitalization (and vice versa).

To interpret the effect of these two variables, we thus compute marginal effects (MEs).[5] Considering that the model presented in Section 4.3.3 can be expressed as

$$\ln(y + 0.7) = \beta_1 x_1 + \beta_2 x_2 + \beta_{1,2} x_1 x_2 + other + \varepsilon \tag{9}$$

where y is *NSRISK*, x_1 is ΔAER, x_2 is Tier 1 ratio, *other* denotes the contribution of the other independent variables, ε is the zero mean error component, the marginal effects of x_1 and x_2 are

$$ME_1 = \exp(\beta_1 x_1 + \beta_2 x_2 + \beta_{1,2} x_1 x_2 + other) E(e^{\varepsilon}) (\beta_1 + \beta_{1,2} x_2) \tag{10}$$

$$ME_2 = \exp(\beta_1 x_1 + \beta_2 x_2 + \beta_{1,2} x_1 x_2 + other) E(e^{\varepsilon}) (\beta_2 + \beta_{1,2} x_1) \tag{11}$$

respectively. We notice that final factors in above equations are what distinguish the two MEs and determine their signs, which depend on the values of the beta coefficients and the variables involved. In a situation (as in this paper) where the interaction parameter $\beta_{1,2}$ is negative, we have:

$$ME_1 < 0 \Leftrightarrow x_2 > -\beta_1 / \beta_{1,2}$$

$$ME_2 < 0 \Leftrightarrow x_1 > -\beta_2 / \beta_{1,2}.$$

In the estimated model (Table 4), by replacing the two coefficients with the estimated counterparts ($\beta_1 = 5.362, \beta_2 = -0.323, \beta_{1,2} = -35.132$), we have $ME_{\Delta AER} < 0 \Leftrightarrow Tier1ratio > 0.156$ and $ME_{Tier1ratio} < 0 \Leftrightarrow \Delta AER > -0.009$.

Fig. 1 reports the values of the two variables for all observations and the quadrants identifying the signs of the two MEs: for 43 observations (26.4%), both MEs are negative; for 24 observations (14.7%), $ME_{\Delta AER} < 0$ and $ME_{Tier1ratio} > 0$; for 70 observations (42.9%), $ME_{\Delta AER} > 0$ and $ME_{Tier1ratio} < 0$; and for 26 observations (16.0%), both MEs are positive.

The majority of the analyzed banks (59.9%) are such that an increase in ΔAER is related to an increase in the company's systemic risk, as reflected by the (slightly) positive $ME_{\Delta AER}$ at the mean (0.005); at the same time, the majority of banks (69.3%) are such that an increase in Tier 1 ratio is related to a decrease in the company's systemic risk, in line with the negative $ME_{Tier1ratio}$ at the mean (−0.332).

Other variables emerge as significant in explaining systemic risk, according to their standalone coefficients. Specifically, bank size is a significant driver of systemic risk. Our findings corroborate the belief that larger banks contribute to the fragility of the financial system, as they are usually more complex, more interconnected, less substitutable, and cause higher losses in the case of default than smaller banks (Bostandzic and Weiß, 2018).

In addition, systemic risk shows a significant relationship with the quality of the banks' loan portfolio. This result confirms that a low quality in credit portfolio results in an increase in banks' likelihood of becoming insolvent and exposes banks to systemic failure (Bartram et al., 2007).

Our empirical evidence also supports that banks' operational efficiency impacts their systemic risk. Less efficient banks are riskier than banks operating with higher levels of efficiency due to their inadequate risk monitoring and consequent concerns about financial risks (Berger and De Young, 1997; Williams, 2004; Fiordelisi et al., 2010).

Furthermore, we find that banks' systemic risk is influenced by country-specific elements. Nordic and peripheral countries seem to contribute to the vulnerability of the financial sector more than GIIPS countries. While the national regulatory systems and deposit insurance schemes are not relevant in our analysis since our sampled banks are subject to uniform rules within the European Single Supervisory Mechanism, other country-specific elements, e.g., the size of the national banking system and its degree of cross-border activities, may affect banks' systemic risk.

6. Conclusion

Due to the relevant changes that have characterized banks' funding structure and asset portfolios in recent years, banks' level of *AE* has rapidly increased. These developments have raised concerns about the implications of increased collateralization of financial transactions for the stability of the financial system. In response to this trend, in 2014, the EBA introduced guidelines on disclosures regarding encumbered and unencumbered assets. Using information disclosed by banks starting from that time, this paper has a threefold aim. First, we investigate the main determinants of *AE* to widen the empirical evidence on the topic. Second, we analyse the effect of *AE* on banks' systemic risk, which is one of the main concerns of supervisors. Third, we examine the impact of *AE* dynamics by assessing whether a change in the level of encumbered assets, either individually or moderated by other bank-specific factors, might affect financial stability. In particular, we use *SRISK* as a proxy for evaluating the systemic risk contributed by a given bank.

[5] We recall that the ME of the variable x_j is the first derivative in x_j of the mean of the dependent variable conditionally on the independent variables.

Table 4
Models for *NSRISK* and *SRISK* as a function of *AER* and Δ*AER*.

	NSRISK	NSRISK	SRISK	SRISK
	(1)	(2)	(3)	(4)
ΔAER	5.362 *	4.777 *	4.594 *	4.538 *
	(2.094)	(2.044)	(2.205)	(2.213)
Size	0.201 *	0.199 *	0.615*** (0.094)	0.619***
	(0.084)	(0.085)		(0.094)
Tier 1 ratio	-0.323	-0.331	0.402	0.734
	(1.208)	(1.197)	(1.280)	(1.299)
(Tier 1 ratio) × ΔAER	-35.132**	-32.031** (12.296)	-27.203 * (13.285)	-26.807 * (13.312)
	(12.617)			
log(Debt maturity)	-0.001	0.007	0.033	0.026
	(0.043)	(0.043)	(0.046)	(0.046)
Business model	-0.400	-0.428	-0.005	0.130
	(0.440)	(0.441)	(0.470)	(0.480)
log(Asset quality)	0.152 *	0.124	0.053	0.084
	(0.068)	(0.071)	(0.072)	(0.077)
RWA density	0.213	0.373	0.360	0.335
	(0.526)	(0.518)	(0.561)	(0.564)
			0.302	0.330
Loans to deposits	0.127	0.015		
	(0.158)	(0.164)	(0.170)	(0.179)
Cost income	1.063**	1.020**	0.347	0.276
	(0.355)	(0.349)	(0.377)	(0.379)
ROA	4.760	4.748	16.577	15.214
	(7.966)	(7.858)	(8.529)	(8.582)
AER	0.196	0.150	-0.070	0.034
	(0.371)	(0.369)	(0.393)	(0.401)
Sovereign yield		0.036		-0.022
		(0.024)		(0.026)
ΔGDP per capita		-0.999		-0.824
		(0.571)		(0.618)
GIIPS	0.421	0.396	0.068	0.071
	(0.308)	(0.310)	(0.346)	(0.347)
Nordic	1.631***	1.741***	1.723*** (0.471)	1.652***
	(0.421)	(0.429)		(0.479)
Peripheral	1.120**	1.028*	1.269**	1.358**
	(0.425)	(0.435)	(0.478)	(0.487)
Year 2016	-0.192***	-0.218*** (0.042)	-0.172*** (0.044)	-0.183*** (0.045)
	(0.042)			
Year 2017	-0.131**	-0.132**	-0.105 *	-0.102 *
	(0.048)	(0.047)	(0.051)	(0.050)
Year 2018	0.129 *	0.116 *	0.075	0.075
	(0.052)	(0.051)	(0.055)	(0.055)
Constant	-2.375	-2.343	0.800	0.850
	(1.461)	(1.453)	(1.610)	(1.612)
Observations	163	163	163	163
R^2	0.470	0.497	0.646	0.650
Adjusted R^2	0.404	0.426	0.602	0.601
F Statistic	125.288***	137.822***	130.937***	132.821***

Note: Panel regression analysis of *SRISK* as a function of *AER* and other explanatory variables (details in Section 4.3.3). *Year* and *Geographical Area* are fixed effects; *Banks* are random effects. Columns 1 and 2 refer to ln (*NSRISK* + 0.7) while columns 3 and 4 refer to ln (*SRISK* + 3500) as the dependent variable. Standard errors are in parentheses. Symbols are as follows (p denotes the p value): *p < 0.05; * *p < 0.01; * **p < 0.001.

Our findings partially confirm the hypotheses that we posed based on the literature. Specifically, bank capitalization is one of the main drivers of *AE*, but the relationship is not monotonic. An increase in capitalization levels tends to reduce the amount of *AE*: higher bank capitalization may induce creditors to ask for lower risk premia, thus reducing banks' need to rely on secured instruments to cut their cost of funding. Nevertheless, the effect of bank capital on *AE* tends to decrease as capitalization increases. In addition, *AE* is positively related to a worsening of sovereign financial conditions, confirming information obtained by the Committee on the Global Financial System (2013). On the other hand, our findings do not support previous research results, according to which the level of *AE* is also determined by bank profitability and the level of credit deterioration (European Banking Authority, 2016; Berthonnaud et al., 2021). This may be driven by a change in the type of operations that have resulted in the use of encumbered assets over time. In more recent years, *AE* has mostly been derived from central bank facilities, not strictly related to banks' profitability profiles and the risk of their credit assets.

Regarding the impact of a change in *AE* on systemic risk, interesting results emerge from the analysis. The *AER* yearly change (*ΔAER*) is significantly associated with *SRISK,* so that an increase in *AE* may lead to a worsening of bank systemic risk. If we analyse the trend of the indicator, it is then possible to obtain valuable information in relation to bank risk. This confirms empirically in a wide sample of banks the results of the case analysis carried out by the ECB, according to which changes in *AE* can contribute to the accuracy

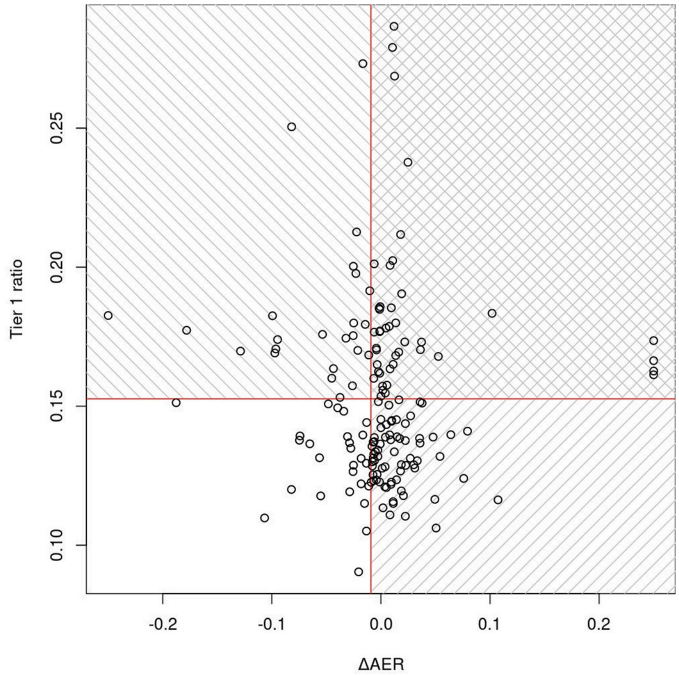

Fig. 1. Marginal effects of Δ*AER* and Tier 1 ratio for each observation. Note: The south-west to north-east shaded area denotes the region where $ME_{Tier1ratio}$ is negative; similarly, the north-west to south-east shaded area shows the region with a negative $ME_{\Delta AER}$. The two red lines are the thresholds.

of an early warning model for predicting bank crises (Berthonnaud et al., 2021). In addition, our findings are noteworthy in light of the concerns of the European Systemic Risk Board (2013) about the potential severity of encumbrance changes, especially when variations are unexpected and unsecured creditors are not able to add the effects of structural subordination to spreads. Thus, the identification of shifts in *AE* is of great importance from a prudential supervision point of view due to their effect on systemic risk. Nevertheless, the increase in *AE* cannot be evaluated separately from other bank characteristics. Specifically, a significant moderating effect is played by bank capitalization. On average, Δ*AER* is significant in explaining banks' systemic risk, but its effect is different depending on banks' Tier 1 ratio. On average, bank capitalization reduces systemic risk, but its impact changes according to the Δ*AER* value. When the level of bank capitalization is particularly low, the structural subordination effect of *AE* may be stronger for the bank than the beneficial effects, by increasing the risk that a growing level of *AE* may impact the bank's future funding capacity, especially in a stressed market environment.

In this situation, investors may start demanding more collaterals to secure their lending as they become more concerned about the bank's financial stability. In addition, an economic downturn usually triggers a reduction in the value of assets, so that more collaterals will need to be pledged to raise a given level of funding, leading to greater levels of overcollateralization. In turn, an increase in the level of overcollateralization may force banks to maintain enough liquidity buffers to meet future calls for additional collateral assets caused by a broad decline in asset prices, reducing the liquidity injected in the market. A higher level of assets encumbered also means that lower unsecured assets will remain available for unsecured creditors, who may start demanding higher interest rates for their lending, increasing overall funding costs. All these effects are amplified when banks have a low level of capitalization. This is a significant result for supervisory authorities, given that in general, *AE* encourages banks to increase leverage, as supported by Helberg and Lindset (2014). The phenomenon needs to be adequately regulated because an increase in *AE* leads to higher leverage, but higher leverage combined with a growth in *AE* determines negative effects on systemic risks.

Prudential supervision based mainly on bank capital requirements should be implemented in an integrated manner to take into account the bank's overall composition of funding sources and the level of collateralization. The integrated analysis of the trend of capitalization and encumbrance ratios is intended to signal information not already known to regulators and supervisors based on conventional drivers of systemic risk. The main results of our study suggest the need for an increase in the level of disclosure on encumbered assets and the introduction of limits on the combined phenomena of high encumbrance and high leverage.

Compliance with Ethical Standards

All authors declare that they have no conflicts of interest.

CRediT authorship contribution statement

Fabrizio Cipollini: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Supervision, Writing – original draft, Writing – review & editing. **Federica Ielasi:** Conceptualization, Methodology, Resources, Data curation, Supervision, Formal analysis, Writing – original draft, Writing – review & editing. **Francesca Querci:** Conceptualization, Methodology, Resources, Data curation, Supervision, Formal analysis, Writing – original draft, Writing – review & editing.

Data Availability

Data will be made available on request.

Appendix

Table A.1
Breakdown of the sample by banks' headquarters.

Ticker	Company	Country
ADKO	Addiko Bank	Austria
BG	BAWAG Group	Austria
EBS	Erste Group	Austria
RBI	Raiffeisen Bank International	Austria
KBC	KBC Group	Belgium
BOCH	Bank of Cyprus	Cyprus
HB	Hellenic Bank	Cyprus
DANSKE	Danske Bank	Denmark
SYDB	Sydbank	Denmark
NDA	Nordea Bank	Finland
BNP	BNP Paribas	France
ACA	Credit Agricole	France
GLE	Societe Generale	France
CBK	Commerzbank	Germany
DBK	Deutsche Bank	Germany
ALPHA	Alpha Bank	Greece
EUROB	Eurobank Ergasias	Greece
ETE	National Bank of Greece	Greece
TPEIR	Piraeus Bank	Greece
OTP	OTP Bank	Hungary
AIBG	AIB Group	Ireland
BIRG	Bank of Ireland	Ireland
IL0A	Permanent TSB	Ireland
BMPS	Banca MPS	Italy
BPSO	Banca Popolare di Sondrio	Italy
BST	Banca Sistema	Italy
BAMI	Banco BPM	Italy
BDB	Banco Desio	Italy
BPE	BPER Banca	Italy
CE	Credito Emiliano	Italy
CVAL	Credito Valtellinese	Italy
ISP	Intesa Sanpaolo	Italy
MB	Mediobanca	Italy
UCG	Unicredit	Italy
SAB1L	Siauliu Bankas	Lithuania
BOV	Bank of Valletta	Malta
ABN	ABN Amro	Netherlands
INGA	ING Group	Netherlands
NIBC	NIBC	Netherlands
BHW	Bank Handlowy w Warszawie	Poland
MIL	Millennium Bank	Poland
PKO	PKO Bank	Poland
NLBR	Nova Ljubljanska Banka	Slovenia
SAN	Banco Santander	Spain
BKIA	Bankia	Spain
BKT	Bankinter	Spain
BBVA	BBVA	Spain
CABK	CaixaBank	Spain
SAB	Sabadell	Spain
UNI	Unicaja	Spain

(*continued on next page*)

Table A.1 (*continued*)

Ticker	Company	Country
SEBA	Skandinaviska Enskilda Banken	Sweden
SHBA	Svenska Handelsbanken	Sweden
SWEDA	Swedbank	Sweden

Table A.2
The total assets of the sampled banks compared to the banking system of their home countries, the analysed regions, and the EU (2019).

Area	Total	Sample	Ratio
Austria	850,482	403,976	47.50%
Belgium	519,249	290,591	55.96%
Cyprus	45,381	37,407	82.43%
Denmark	855,252	523,160	61.17%
Finland	718,889	554,848	77.18%
France	7279,938	5288,851	72.65%
Germany	6044,163	1761,124	29.14%
Greece	258,113	253,698	98.29%
Hungary	80,845	60,877	75.30%
Ireland	232,207	152,196	65.54%
Italy	2679,217	2263,514	84.48%
Malta	22,253	12,331	55.41%
Netherlands	2329,405	1266,798	54.38%
Poland	255,882	116,940	45.70%
Spain	3497,232	3127,800	89.44%
Sweden	999,538	797,808	79.82%
Core	17,023,237	9011,340	52.94%
GIIPS	6666,768	5797,208	86.96%
Nordic	2573,679	1875,816	72.88%
Peripheral	404,360	227,555	56.28%
EU	26,668,044	16,911,919	63.42%

Note: At the bottom of the table, the region *Nordic* include the following countries: Denmark, Finland, and Sweden; *GIIPS* is an acronym of Greece, Italy, Ireland, Portugal, and Spain; *Peripheral* groups together Hungary, Malta, and Poland; *Core* include all the other countries. *EU* encompasses the countries considered in the analysis.

Table A.3
Descriptive statistics of the variables considered in the analysis, by region (2014–2019).

Variable	Statistic	Core	GIIPS	Nordic	Peripheral
AER	mean	19.69%	26.05%	27.94%	8.03%
	st. dev.	7.39%	11.42%	8.86%	9.05%
AERs	mean	14.17%	25.48%	26.40%	8.27%
	st. dev.	4.64%	11.35%	9.68%	8.92%
Business model	mean	59.79%	53.98%	56.57%	61.59%
	st. dev.	10.94%	140.87%	10.09%	7.60%
NPL ratio	mean	4.53%	16.62%	1.29%	15.65%
	st. dev.	2.94%	13.75%	1.18%	17.72%
ROA	mean	2.41%	2.61%	1.85%	4.04%
	st. dev.	0.91%	0.63%	0.57%	1.47%
Size	mean	13.062	11.555	12.273	9.894
	st. dev.	1.453	1.366	1.142	0.749
Leverage	mean	5.45%	6.83%	5.14%	8.83%
	st. dev.	2.38%	2.20%	1.13%	1.67%
Sovereign yield	mean	0.59%	2.60%	0.63%	2.74%
	st. dev.	0.45%	2.16%	0.47%	0.94%

Note: The region *Nordic* include the following countries: Denmark, Finland, and Sweden; *GIIPS* is an acronym of Greece, Italy, Ireland, Portugal, and Spain; *Peripheral* groups together Hungary, Malta, and Poland; *Core* include all the other countries.

Table A.4
Descriptive statistics of the variables considered in the analysis, by bank (2014–2019).

Bank	Country	AER		AERs		Business model		NPL ratio		ROA		Size		Leverage	
		mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.	mean	st. dev.
ADKO	Austria	7.02%	0.82%	7.36%	0.94%	66.13%	5.84%	11.22%	4.26%	4.03%	0.69%	8.78	0,08	12.64%	1.29%
EBS	Austria	14.42%	0.79%	14.62%	0.74%	63.25%	1.63%	4.75%	2.27%	3.24%	0.30%	12.29	0,09	6.53%	0.68%
RBI	Austria	10.43%	1.37%	8.96%	1.13%	65.21%	2.49%	6.65%	3.07%	4.02%	0.36%	11.76	0,12	7.22%	0.69%
KBC	Belgium	15.23%	1.48%	15.79%	1.63%	60.71%	2.82%	6.10%	2.24%	2.68%	0.11%	12.52	0,08	5.82%	0.28%
BOCH	Cyprus	15.43%	0.68%	15.45%	0.67%	54.04%	1.50%	35.61%	9.50%	3.67%	0.65%	10.01	0,06	9.59%	0.43%
HB	Cyprus	1.37%	1.23%	2.81%	2.51%	63.17%	7.35%	48.77%	13.22%	3.11%	0.81%	9.15	0,42	8.08%	1.52%
DANSKE	Denmark	42.69%	0.85%	41.10%	1.26%	64.92%	6.60%	2.68%	1.04%	1.37%	0.07%	13.06	0,04	4.33%	0.21%
SYDB	Denmark	10.14%	1.34%	6.70%	3.10%	50.90%	6.56%	2.67%	1.24%	3.03%	0.25%	9.87	0,04	7.46%	0.13%
NDA	Finland	28.04%	2.35%	27.85%	3.50%	50.33%	2.30%	0.81%	0.05%	1.57%	0.06%	13.31	0,08	4.51%	0.47%
ACA	France	15.02%	5.62%	15.02%	5.62%	64.95%	5.90%	3.31%	0.87%	1.13%	0.08%	14.28	0,06	2.67%	0.18%
BNP	France	24.34%	3.45%	13.40%	2.28%	49.67%	2.33%	4.93%	0.92%	2.11%	0.12%	14.53	0,04	3.96%	0.32%
GLE	France	29.20%	3.13%	13.14%	1.56%	40.72%	3.86%	5.25%	1.25%	1.90%	0.07%	14.10	0,02	3.73%	0.19%
CBK	Germany	28.54%	4.25%	21.85%	7.76%	54.21%	5.85%	2.71%	1.39%	1.87%	0.15%	13.10	0,09	5.29%	0.45%
DBK	Germany	25.82%	3.35%	14.75%	1.94%	50.02%	5.28%	1.83%	0.25%	1.88%	0.09%	14.22	0,11	3.78%	0.23%
ALPHA	Greece	34.70%	12.99%	34.32%	13.26%	76.80%	7.83%	47.09%	9.37%	3.68%	0.42%	11.09	0,07	12.99%	1.48%
ETE	Greece	19.66%	16.29%	18.49%	15.68%	89.85%	10.27%	34.75%	5.20%	2.13%	0.40%	11.30	0,27	8.54%	0.98%
EUROB	Greece	2.28%	2.54%	0.38%	0.93%	80.24%	4.26%	38.98%	5.73%	2.75%	0.39%	11.10	0,11	9.79%	1.28%
TPEIR	Greece	27.92%	16.69%	27.67%	16.82%	77.13%	5.89%	42.09%	5.96%	2.96%	0.34%	11.21	0,17	10.40%	1.36%
OTP	Hungary	5.75%	1.00%	5.84%	0.92%	67.64%	6.19%	13.10%	5.12%	6.80%	0.85%	10.63	0,22	9.24%	1.09%
BIRG	Ireland	18.69%	3.89%	18.18%	3.83%	75.42%	2.87%	10.20%	4.86%	2.35%	0.15%	11.75	0,04	6.01%	0.55%
IL0A	Ireland	36.06%	19.34%	36.05%	19.34%	-188.10%	673.88%	20.29%	9.47%	1.46%	0.88%	10.13	0,22	7.88%	1.16%
BAMI	Italy	33.06%	0.73%	33.13%	0.72%	51.07%	3.68%	19.91%	8.54%	2.53%	0.24%	11.85	0,17	5.14%	0.66%
BDB	Italy	10.18%	4.21%	17.46%	7.40%	57.25%	2.36%	10.88%	4.52%	3.14%	0.41%	9.48	0,07	6.74%	0.53%
BMPS	Italy	36.95%	2.19%	35.04%	2.95%	48.04%	4.27%	26.67%	10.73%	2.64%	0.33%	11.93	0,14	5.03%	1.42%
BPE	Italy	25.17%	5.80%	25.11%	5.82%	57.77%	3.61%	18.31%	5.39%	3.10%	0.43%	11.12	0,10	6.81%	0.59%
BPSO	Italy	18.88%	6.16%	19.36%	6.39%	54.65%	3.60%	14.57%	2.47%	2.48%	0.39%	10.56	0,08	6.63%	0.23%
BST	Italy	20.63%	2.64%	20.63%	2.64%	83.94%	3.31%	7.92%	0.90%	3.31%	0.63%	7.91	0,28	5.23%	0.57%
CE	Italy	33.68%	2.92%	33.35%	2.00%	46.65%	4.80%	5.03%	1.21%	2.73%	0.19%	10.61	0,11	4.62%	0.40%
CVAL	Italy	31.88%	6.01%	31.92%	5.70%	62.83%	9.25%	19.27%	8.86%	2.59%	0.43%	10.17	0,06	6.83%	0.84%
ISP	Italy	25.67%	3.43%	23.90%	3.10%	49.21%	9.42%	13.25%	4.10%	2.31%	0.20%	13.51	0,10	5.59%	0.22%
MB	Italy	28.78%	4.14%	25.01%	4.92%	65.97%	3.64%	5.42%	1.01%	2.78%	0.31%	11.22	0,06	9.07%	0.71%
UCG	Italy	28.69%	0.94%	25.52%	1.55%	58.42%	1.55%	11.08%	4.49%	2.24%	0.19%	13.65	0,01	5.65%	0.96%
BOV	Malta	10.49%	19.09%	10.49%	19.09%	59.71%	2.60%	6.19%	1.28%	2.24%	0.20%	9.32	0,12	6.01%	1.07%
ABN	Netherlands	23.06%	0.55%	16.60%	1.17%	73.34%	2.99%	2.55%	0.42%	2.28%	0.14%	12.86	0,02	5.28%	0.52%
INGA	Netherlands	18.29%	0.67%	11.75%	0.41%	76.12%	2.76%	2.07%	0.25%	1.90%	0.34%	13.75	0,13	5.33%	1.07%
BHW	Poland	2.88%	1.73%	2.88%	1.72%	50.21%	2.24%	3.79%	0.82%	4.52%	0.29%	9.33	0,07	10.28%	0.71%
MIL	Poland	16.88%	2.86%	16.88%	2.86%	63.86%	4.04%	4.54%	0.05%	3.60%	0.18%	9.75	0,17	8.89%	0.41%
PKO	Poland	6.71%	1.00%	6.71%	1.00%	68.74%	3.03%	5.69%	1.06%	4.16%	0.18%	11.14	0,13	10.07%	0.83%
BBVA	Spain	20.75%	1.78%	18.35%	2.22%	72.87%	2.04%	4.93%	0.89%	3.23%	0.20%	13.45	0,06	6.78%	0.22%
BKIA	Spain	41.08%	6.59%	41.68%	6.81%	69.21%	4.47%	9.10%	3.18%	1.59%	0.18%	12.25	0,07	5.72%	0.58%
BKT	Spain	25.72%	3.29%	24.36%	2.92%	60.27%	6.12%	3.93%	0.90%	2.41%	0.23%	11.13	0,15	5.30%	0.20%
CABK	Spain	23.32%	3.58%	23.70%	4.18%	63.09%	1.84%	6.39%	2.18%	2.03%	0.10%	12.81	0,07	5.11%	0.23%
SAB	Spain	31.76%	5.62%	32.02%	5.53%	66.97%	9.14%	6.71%	3.53%	2.44%	0.21%	12.24	0,12	5.00%	0.18%
SAN	Spain	25.86%	1.23%	23.13%	0.99%	70.90%	2.44%	4.18%	0.56%	3.37%	0.11%	14.15	0,07	5.33%	0.16%
SEBA	Sweden	23.55%	1.38%	18.87%	1.63%	44.18%	1.59%	0.59%	0.10%	1.75%	0.06%	12.50	0,04	5.07%	0.36%
SHBA	Sweden	27.84%	3.82%	27.53%	3.71%	71.23%	1.58%	0.40%	0.05%	1.49%	0.08%	12.56	0,04	4.49%	0.40%
SWEDA	Sweden	26.48%	1.38%	26.48%	1.38%	57.88%	1.84%	0.58%	0.16%	1.88%	0.08%	12.33	0,02	4.98%	0.33%

Note: The region *Core* include the following countries: Denmark, Finland, and Sweden; *GIIPS* is an acronym of Greece, Italy, Ireland, Portugal, and Spain; *Peripheral* groups together Hungary, Malta, and Poland; *Nordic* include all the other countries.

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