Analyzing Risk Exposure Determinants in European Banking: A Regulatory Perspective

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Abstract

The paper deals only with the identification of the determinants of total risk exposure amount within the European banking system, while the importance of TREA within Basel III regulatory regimes is focused. The research provides the integration of an econometric investigation with high-end machine learning techniques for the identification of the influential financial variables of TREA. The most relevant financial determinants of TREA were identified as LCR, CRWEA, LA, and OREA. These also reflect complex interdependencies-for instance, the negative value of TREA and LCR would suggest that there were trade-offs made between risk-taking and liquidity management. Thus, the positive relationship with CRWEA, and even more so with derivatives over assets, underlines intrinsic risks from credit exposures and related to financial instruments' complexity. The report further iterates that there should be mechanisms for appropriate risk-weighting, adequate liquidity buffers, and proper operational controls so that the financial system can become significantly more stable and resilient. This work will put forward actionable recommendations to policy makers, regulators, and financial institutions on mitigating systemic vulnerabilities and further optimizing their strategies for compliance in view of an increasingly volatile financial landscape, leveraging from traditional econometric modeling insights with machine learning.

Keywords: Total Risk Exposure Amount, European Banking System, Liquidity Coverage Ratio, Risk Management, Basel III Compliance.

JEL CODES: G21; G28; G32; G53; E58.

1. Introduction

The Total risk exposure amount-TREA forms one of the cornerstones of modern banking regulatory architecture and is very pervasive in Europe; it represents a composite measure of categories of risks-like credit, market, and operation risks-to which a bank is exposed. This reflects the regulatory requirements of frameworks like Basel III. While TREA acts as a determinant for capital sufficiency, in that respect, it has an essential bearing on the solvency of banks, which, in turn, translates into stability in the greater banking system. Fundamentally, the dynamics or impacts TREA makes in some variables-for instance, liquidity coverage ratios, credit risk exposure, credit booking, and loans advancements, and/or operation risks-they signal much fundamentally at what depth some mitigation measures reach toward critical prudential operational risk in a given sector. This is well understood in the European context, where different economic structures, regulatory environments, and financial ecosystems exists. European banks have to build a vision in an environment that is complex and interwoven with high regulatory requirements, technology advancement, and fluctuating economic conditions. The period from 2019 to 2024 was remarkable on account of macroeconomic uncertainties, changing market dynamics, and increased systemic stability focus. These factors therefore underpin the need for an analysis of the determinants of TREA as a means to understand vulnerabilities and mechanisms for resilience in banking. The present paper explores the study of the determinants of TREA in the European banking system through an application of a complete econometric framework along with machine learning-advanced models. These may include variables like the Liquidity Coverage Ratio (LCR), Credit Risk-Weighted Exposure Amounts (CRWEA), Loans and Advances (LA), Net Liquidity Outflows (NLO), Liquidity Buffers (LB), Derivatives-Assets (DA), Operational Risk Exposure Amount (OREA), and Intangible Assets and Goodwill (IAG). The given study throws light on the complex relationships defining the risk exposure of banks. These are variables of regulatory importance but also relate to risk management, policy formulation, and financial stability.

It also underlines at the same time the trade-offs that must be balanced by the banks. To explain, for instance, a negative relation of TREA with LCR would denote the trade-off between risk-taking and liquidity management; such banks would rather be disposed to maintain more than the required capital, rather than retaining an excessive buffer of liquidity. There will, therefore, always be active challenging areas to full compliance with this regulation on liquidity requirements, linking credit risk and, indeed, the resulting financial stability. The contrary is that the correlation between TREA and CRWEA is positive; just underlines further the connection that exists in prudential management between credit risk and total risk exposure. Conclusively, the paper, therefore, for the first time, presents research into how TREA might interact with such salient financial elements as operational risk, liquidity buffers, and derivatives to assets within the context of an overview, providing some insight into the nature of risk landscapes in European banking. Machine learning techniques of this nature support the development of more robust predictive drivers of TREA, whose application would be pivotal in the methodology of the Support Vector Machines. In their implementation come sets of tools that bring out a deeper level of understanding about how the relationships of the variables elicit effective risk assessments while the regulatory compliance quotient is heightened. The present study thereby bridges the gap between traditional econometric modeling and current state-of-the-art technological development, setting new frontiers within the risk management field. However, the TREA determinants are not only of academic interest but also highly relevant for policymakers. Policymakers and regulators may use the findings to develop improvements in risk-weighting schemes, liquidity requirements, and standards in risk management. The findings have to be beneficial for banks with regard to mapping their strategy in relation to regulatory expectations and enhancement of resistance toward financial shocks. It further underlines the role that technological innovation alone can play toward risk management and how AI-driven tools can make all the difference, so to say, in conceptualizing risk assessment and mitigation on the part of banks. The detailed analysis of the TREA determinants in the European banking system forms the conclusion of the paper for useful insight into the higher order objective of policymakers, regulators, and financial institutions. This adds to the literature through the investigation of the interactions of risk factors using advanced tools for analysis to arrive at the higher order objective of stability and resilience in the banking sector. These results really drive home the balance required between risk-taking and prudential oversight, with innovation being an enabler of both in an increasingly challenging environment for banking.

The article continues as follows: the second section presents the literature review, the third section shows the data, the fourth section presents the econometric model, the fifth section analyzes the machine learning regressions, the sixth section presents the machine learning algorithms for clustering, the seventh section contains the policy implications, the eighth section concludes.

2. Literature Review

Banking Risks and Stability. Abad et al. (2022) document how EU banking associates with the global shadow banking system on both the supply side and intermediation side, indicating just indirect exposures across intricately connected complex financial instrumentality to amplify systemic vulnerability factors. This is because the granular mapping presented commends a limited number of pieces of information on substantial discussion points with which questions to be raised will bring forth needed actionable strategies for risk regulators. Adem, (2023) gives the interrelationship of macroprudential policies and political institutions in credit risk mitigation in Ethiopian banking and further leads to fresh insights on the ways in which institutional quality may affect the resilience of banks within developing economies. However, this could be even stronger if it adopts a more comparative approach, especially with other African countries. Agha et al. (2023) focus on the banking sector of Nigeria and analyze how the weak governance mechanism is causing deterioration in asset quality and increased systemic risk. Their recommendations about the reforms that should be carried out in the governance structure are fairly realistic; however, the paper would have better value in placing such insight into the broader perspectives of banking governance changes occurring around the world. The contribution of Ahamed, (2021) delves into investigating causes of liquidity risk in the case of commercial banks of Bangladesh and, therefore, both internal issues with capital sufficiency, as well as an externally induced factor in the form of monetary policy variable. Good contribution, perhaps one would take further by at least comparative considerations over other similarly circumstanced regional economies-members of SAARC or regional developing economies dealing with similar phenomena of banking sector liquid liabilities.

Borri and Di Giorgio, (2022) present an overview of changing systemic risk for the European banking system during the period related to COVID-19. Their attempt to identify, by means of empirical approaches, would allow one to consider that this given crisis has increased the amplitude of financial fragility and interconnections. As timely and enlightening as the study might be, there is a feeling that more was due by way of a longer-term analysis of pandemic-driven regulatory actions. Ellis et al. (2022) present a critical review of some widely known systemic risk measures from the viewpoint of appropriateness under regulations. This piece of work might be quite useful for policy framers indeed, since, in reality, they bridge the gaps between theoretical model risks and actual applications, with further added value through case studies on real stress-testing scenarios. Jakubik and Moinescu (2023) consider the optimal capital ratio for stability in the European banking system, efficiency versus resilience. Their modeling is quite sophisticated and really does provide valuable insights; however, recommendations from these studies face challenges in implementation due to the diversity of the banking systems across the EU. Lajaunie, (2023), examines profitability and risk drivers in European banks, combining macro- and micro-approaches that balance the framework of bank performance analysis. However, deeper consideration of external shocks could be given more geopolitical risks for further nuances of results. Magnis et al. (2024) set out to look at the relevance of risk-related disclosures in ultimately improving regulatory efficacy, considering this as a transparency enhancement mechanism for lowering information asymmetry for regulators of banking institutions. While they raise the importance of disclosure standardization, the possible challenges of such a scheme in actual implementation within diverse legal frameworks is what the authors would do well to discuss in the paper. Neill, (2024) discusses the effectiveness of EU macroprudential policies in responding to systemic risk and emphasizes the complications arising between balancing national and supranational objectives. Though it is a very relevant study considering recent debates on policy coordination, the implications of its findings could be extended further, especially toward the consequences for non-EU economies that are closely related to the EU. Serrano, (2021) analyzed the effect of NPL on bank lending in Europe and stated that a high level of NPL ratio decreases the credit availability rate, thus hampering economic recovery. This is detailed, yet a longitudinal analysis may have been more appropriate in catching any periodic oscillations of NPLs in various cycles of economies. Soenen and Vander Vennet, (2022) did an empirical study of the default risk determinants of European banks. Strong capitalization would appear to be one of the primary and indeed overriding reasons, accompanied by high governance and quality of assets. The research may be empirically sound, but it confines its scope to Europe; more comparative elements from other parts of the world would arguably increase the applicability of such work. Stellinga, (2021) delivers a historical analysis related to the EU's macroprudential policy by describing how it first emerged and then stalled in terms of political and institutional barriers. While the identification of barriers is well delivered, more actionable recommendations on overcoming such challenges would have further enhanced the practical utility of the work. Taken together, these articles outline the multidimensional challenges facing the world's banking sector.

Regulatory Frameworks and Macroprudential Policies. Altunbaş et al. (2022) attracted wide attention to the fact that SSM influences several dimensions of risk disclosures in European banks, that SSM increases seriously the level of transparency and harmonization in regard to the nature of disclosed risks. The paper underlined quite effectively how summarized supervision might improve market discipline but at the same time gave the red light as regards the danger related to excessive compliance costs for small banks. Budnik et al. (2023), presented the BEAST model for estimating systemic-wide risk with macroprudential policy analytic value and introduced a new computation capability toward interlinkage assessment in financial systems. Although promising applications are provided for stress testing and policy evaluation, Chen et al. (2024), have done more research in that line, which needs to be done because most of the ideas remain conceptual, with an overall lack of information about how this already constructed model works and exactly how detailed examples of practical implementation in other diverse markets are shown. Chen et al. (2024) researched financial openness, banking systemic risk, and macroprudential supervision. According to the observation, greater openness of finance worsens the systemic vulnerabilities unless commensurate and vigorous macroprudential responses are made. The value of this article is in pointing out the proper balance that needs to occur between liberalization and strong supervision, although it had the potential of being further developed to consider the contrasts between advanced and emerging economies. Fernández Fernández (2023) points to the fact that, even while the structures and dynamics of the European Banking Union have been exceptionally successful in both reaching integration and building resilience, it had remained plagued by pending challenges seriously hampering the process of reaching integration: political fragmentation and unequal implementation at the member state level. It gives a quite balancing stocktake of the union's evolution and might go further into how non-EU external shocks affect its cohesion. Following Guerra and Castelli, (2021), discussing machine learning within banking supervision may present just that: how the method can boost the predictive ability of risk analysis while showing caution against dependence on nontransparent algorithms. It may well be what speaks most for the authors in this paper: the fact is that techniques concerning machine learning are complementary to, not a substitute for, more traditional supervision methodologies. In fact, this would all be the more pointed given that more discussion is raised about ethical concerns and biases in algorithmic decision-making. The work of Matos et al. (2024), also examines how macroprudential regulation is influenced by the rights of shareholders and creditors. They notice that strong creditor rights ultimately stabilize financial systems because these constrain moral hazard, while strong shareholder rights promote risk-taking. This nuanced view lends depth to the discussions of corporate governance and its interaction with regulatory policy. It is a narrow focus made possible by the analysis of the determinants of banks' credit risk and its macroprudential implications, including capital adequacy, loan quality, and general state of the economy. Indeed, the results have evidenced the key contribution of countercyclical buffers in taming risk, but the paper needs more improvement in aspects that will verify the effects beyond the period of this economic slowdown so far.

Ofori-Sasu et al. (2023) investigate bank risk exposures and stability in Africa, using nonlinear regulation models to illustrate how regulatory intensity interacts with bank stability in various macroeconomic environments. The regional focus offers great insight into the peculiar challenges that the African banking systems have been facing, though broader comparisons with other developing regions would enhance its global applicability. Ojo, (2024) provides insight into new developments in financial stability and macroprudential arrangements. New emergent trends that are said to become significant areas for regulatory development include those of climate risk management and digital innovation. In this way, the strength of the article lays in the forward-looking nature of the approach. Still, at the same time, this broad reach of foresight makes one question exactly how some policies would be put forth. Pacelli and Povia, (2024) discuss the macroprudential policies containing systemic risk that, until now, had never been subject to further development regarding cross-border coordination in addressing global financial vulnerabilities. The focus is internationally relevant, timely, although greater attention should be paid to jurisdiction-specific challenges with respect to the implementation of such policies. In this paper, Petrović and Trifunović, (2024) assess the Basel III Accord as a regulatory framework for risk management. According to the authors, strict capital and liquidity requirements under Basel III have indeed made banking systems more resilient but may dampen credit growth in certain contexts. The authors do a good job of balancing critiques of Basel III's limitations with recognition of its successes; further exploration of its adaptability to non-Western financial systems could be a useful extension of this research. Piroska et al. (2021) discuss how the interaction between supranational regulation and domestic politics plays out within the economies of the EU and surmise that effective regulatory implementation is commonly hindered by political resistance. This study could, therefore, provide an insightful basis from which regulatory fragmentation could be approached by focusing on tensions between national sovereignty and objectives that reach across the union, although an in-depth study about its effect on nonmembers that are close to the union might have added much weight. Riabi, (2021) focuses on the role and positioning of central banks within the macroprudential framework. In this regard, he signals that central banks have double responsibility for price stability and financial stability. This paper underlines the potential tension between the two mandates, particularly with respect to unconventional monetary policies, but it could give more emphasis to how such conflicted monetary decisions are made by the central bank in times of turmoil. Rizwan et al. (2024) focused on how varying country governance levels change the nexus between systemic risk and macroprudential regulations. They find good institutional quality is one of those factors that considerably raise the impact of macroprudential tools. Such a study could indeed be built upon for an in-depth discussion on the significance of governance in this respect, but probably it should have culminated on providing specific case-related insights which most probably could substantiate such findings.

Sustainability and ESG Integration in Banking. Research by Allini et al. (2024), looks at the relation between liquidity risk exposure and earnings management in the European banking sector. It indicates that banks, in their earnings management process, manipulate their earnings to look stable when risks in liquidity may be high. Their contribution is, therefore, useful in the light of the two pulls on banks-

retain solvency and also retain transparency-end. Baldi and Pandimiglio (2022) discuss the risk of green washing in green bonds, which is, however, linked to inconsistent ESG scoring methodologies that ultimately damage green financial instruments' credibility. From this work has emerged the urgency of standardized ESG measures in anti-green washing actions, although certainly more policy could be derived in depth from incentive analysis for real market compliance to ESG itself. Böffel and Schürger (2022) point out the role that sustainability currently plays as a driver for European Union banking regulation, highlighting in that context those fields in which regulatory frameworks already reflect ESG factors in their design to bring financial practices into line with the goals of sustainable development. It concludes that integration of ESG criteria into regulatory mandates is helpful in several ways but points out manifold challenges, amongst others, that the principle of sustainability will be applied more heterogeneously across member states. Bua et al. (2024) measured the cost of climate risk in European financial markets. Indeed, they mentioned that present prices are reflecting only partially a climate risk which may be subject to its mispricing and thus leading to inefficiency. The work rather well illustrates how backward financial markets react to environmental reality, but future research is needed to learn the role of investor education and engagement in the enhancement of climate risk pricing. Chiaramonte et al., (2022) develop an analysis that shows how much ESG strategies play their role in bank stability during turmoil periods and find out that strong ESG practices offer a sort of buffer against systemic shocks. While the cited study indeed indicates and underlines what is related to the stabilizing influence of adopting ESG principles, it could be developed further by even more fine-grained analysis in respect of how each single dimension of ESG-or governance and environmental stewardship-contributes to stability. As argued by De Smet, (2022) nexus linking sustainability and systemic risk in the new EU banking regulations has been addressed to mean setting long-term environmental risks "within a large framework of financial stability.". The present paper adds to the development of the discussion of sustainable finance in that it brings the systemically relevant effect of neglect on climate-related risks and shows how macroprudential policy instruments already available need to be further modified.
Kossmann (2023) discusses ESG regulations from the perspective of their impact on macroprudential policy and banking activities. He believes that the appearance of sustainability in these regulatory frameworks opens up an opportunity but at the same time challenges. This paper underlines the trade-offs quite well between the fostering of sustainability and the traditional financial stability objectives. However, such a study would be even more powerful if it had carried out a comparative analysis across jurisdictions with different ESG maturity levels. Riso (2021) elaborates on the role of prudential supervision in sustainable finance, building an argument that supervisors have to balance their traditional mandates with the need to lead the financial sector toward sustainability. This paper develops insights into the evolving responsibilities of financial regulators but could be extended by analyzing those supervisory practices that successfully drive sustainable outcomes.

Smoleńska, (2023) focuses on the role of central banks in the supervision of ESG risks, showing how microprudential oversight could rise to meet new challenges created by the integration of sustainability into financial systems. It underlines the dual mandate given to central banks to take care of stability while taking care of ESG risks, though this aspect might have been discussed a bit more with respect to the broader macroeconomic policies intersection. In this paper, Smoleńska and van't Klooster (2022) set credit guidance in opposition to microprudential approaches to climate risk and put forward the view that only a mix of proactive credit policies and targeted supervision can really address the systemic nature of climate risks. Although this paper indeed has made a very strong case for the blended approaches on sustainable finance, some of its recommendations could have been more constructive, especially considering how it provides examples in real-life successful credit guidance that might be given in an effort to minimize or, as it were, manage the effects of climate risk. Hughes et al., (2021) step back, setting health and financial cost of adverse childhood experiences within the broader European view - the long-term economic and social cost from adversities in early life. Although the work does not cover or relate directly to financial systems, it outlined such consideration in society and drew an integral linkage from the point of view of well-being society to that one of stability concerning Finances: Hulshof et al. (2021) give a review concerning the contribution of ergonomic risk factors to health problems at work, providing an insight into how the conditions in workplaces are adding up to more public health and economic problems. Their study does provide further reason, however, as to why businesses should be health-sensitive in their ESG agenda-even if its importance can be better contextualized within a debate on corporate liability and regulatory requirements. They do, however, together show that at the heart of financial regulations, risk management, and even the making of economic policy lies sustainability. They also emphasized the interlink of issues from environmental and social challenges to how financial systems will be resilient-issues ranging from themes of the cost of climate risk to green washing and systemic regulation of ESG. The implication of these results is a regulatory framework that evolves adaptively to accommodate innovative classes of financial instruments capable of aligning economic activities along global sustainability vectors. Furthermore, attention to integrating ESG factors into financial practices represents the growing acknowledgment that sustainability is indeed a moral virtue, but more importantly, an important determinant of long-term economic resilience.

3. Data

We have applied the following data from European Central Bank as showed in Table 1.

Table 1. Variables of the model from European Central Bank. Link: https://www.bankingsupervision.europa.eu/framework/statistics/html/index.it.html

Variable	Acronym	Definition
Total risk exposure amount	TREA	In banking, Total Risk Exposure Amount, TREA is the regulatory measure of the bank's overall exposure to various risks, adjusted for their risk levels. Examples of exposures would include credit risk, market risk, and operational risk. These are then assessed by means of risk-weighted assets, with each asset or exposure weighted in line with the possible impact of loss and related regulatory requirements under Basel III, among others. TREA stands at the very heart of a bank's capital adequacy determination, being the denominator for two of the key regulatory ratios: the CET1 ratio. It ensures that banks hold adequate capital to absorb losses and remain solvent in order to maintain financial stability. The larger the TREA, the more a bank is committed to a greater risk exposure and thus the stronger the bank's capital needs to be. In so doing, TREA links risk exposure to regulatory capital and sends an opportunity to make sure the resilience of the banking system against financial and systemic shocks.
Liquidity coverage ratio (%)	LCR	The more important financial ratio to ascertain whether the bank can pay current liabilities in the event of a bank falling into financial distress is termed the Liquidity Coverage Ratio. It expresses, in a percentage form, that proportion of highly liquid assets-cash and government bonds-out of estimated cash outflows over a period, usually within 30 days. This ratio is intended to be a buffer of liquid assets that banks can easily convert into cash to meet potential funding gaps, with the view to increasing the resilience of their liquidity position in periods of economic uncertainty or disruptions to financial market functioning. The greater is the ratio, the better will be the liquidity position of a bank, as it has sufficient high-quality liquid assets that can be transformed into cash against its short-term liabilities. The Liquidity Coverage Ratio goes further to stabilize the economy through facilitation of good liquidity management practices. This ratio has consequently reduced the tendency for runs by banks while at the same time restoring investor confidence and depositors alike.
Credit risk-weighted exposure amounts	CRWEA	Credit risk-weighted exposure amounts are the notional value of the bank's assets and off-balance-sheet items after credit risk adjustments under different sets of regulations, including Basel III. This measure is used in assessing the likelihood of loss due to the failure of borrowers to settle their obligations. A weight is assigned to

		each asset or exposure, which reflects various factors that relate either to the creditworthiness or the probability of default of the asset or exposure. For example, the bonds of a stable economy carry a low or zero risk weights while loans to borrowers with poorer credit or high risks associated with certain investments are ascribed higher weights. By this, the measurement exposure concomitantly reflects the actual risk profile of a bank's asset portfolio. The credit risk-weighted exposures constitute an essential category within the framework of a bank's overall risk exposures and a calculation basis of the regulatory capital requirement. Consequently, the relation of capital buffers with the credit risk level advances the aims of financial stability and lowering of systemic risk.
Loans and advances (total)	LA	Loans and advances-Total: It is the sum total of the funds that the bank has lent to its customers, whether persons, businesses, or other institutions, in respect of its core lending activities. It involves a wide array of credit forms, like personal loans, mortgages, corporate loans, overdrafts, among other advances availed by people to meet the financing needs. Loans and advances are among the major items of assets for any bank and among the main sources of interest incomes. However, they also raise a bank's credit risk since some borrowers cannot repay their loans. To this effect, banks would assess the borrowers' credit standing and book necessary provisions against loan losses. The total loans and advances measure reflects the bank's lending activity and overall credit exposure, underpinning insights into its growth strategy, risk appetite, and market position while serving as an indicator of its contribution to economic activity.
Net liquidity outflow	NLO	In banking, net liquidity outflow is defined as the difference between a bank's expected cash outflows and inflows over a predefined short-term period, usually 30 days, under conditions of financial stress. It measures the net amount of liquid resources that a bank would need to meet its obligations if it happens to be suddenly faced with strained liquidity. The cash outflows will include payments like withdrawals by depositors, maturing liabilities, or loan commitments, while cash inflows will be expected receipts on performing loans, asset sales, or other recoverable funds. Such regulatory frameworks, including Basel III, have laid down detailed guidelines for estimating these flows by even applying stress scenarios in order to test preparedness under adversity. Net liquidity outflow is one of the most crucial factors in managing liquidity and performing the needed regulation. The higher the flow, the more funding requirements rise, which suitably should have an adequate counterbalance in high-liquid quality to cover the mismatch and provide stability in operations when money or institutional market stress arises.
Liquidity buffer	LB	Under banking terminology, it means the amount of high-quality liquid assets available with banks to meet short-term liabilities during periods of stress. Examples include central bank reserves, government securities, and highly rated corporate bonds. The chief purpose of a liquidity buffer would be to serve as a defense or protection against unexpected cash outflows-what would be termed large-scale withdrawals by depositors or disturbances in funding markets. It is one of the most important tools in the management of liquidity risks; hence, the ability of the bank to remain soluble and continue its operations during crises. For instance, the regulatory framework like Basel III provides that there should be adequate liquidity maintained opposite such requirements as the Liquidity Coverage Ratio. Banks that have enough reserves are resilient and add to financial stability to ultimately build confidence in customers and investors.
Derivatives-assets	DA	Derivatives-assets are financial contracts whose value, in banking, is derived from the performance of an underneath asset, index, or benchmark-for example, interest rates, currencies, commodities, or equities. These will appear on the balance sheet when the bank has a positive value position in a derivative contract-the market value of the contract is favorable to the bank at any point in time. The two major uses of derivative-assets by banks for hedging and speculation are the main purposes. In hedging, the derivatives are used to reduce the risks involved in interest rates or foreign exchange rates. They are used for speculative activities to make a profit from the movement of markets. The most widely used derivative instruments include swaps, options, and futures. Though earnings are higher and risks lower from the derivatives-assets, the instruments themselves are complex and carry counterparty risks. Thus, regulatory frameworks also require that banks accurately account for the derivatives-assets and hold adequate capital against loss in order to contain systemic risk.

Operational risk exposure amount	OREA	Operational risk exposure amount in banking refers to the quantified value of potential losses arising from inadequate or failed internal processes, people, systems, or external events. Unlike credit or market risk, operational risk is not directly linked to financial market movements but encompasses a wide range of risks, including fraud, cybersecurity breaches, system failures, legal liabilities, and natural disasters. This exposure is calculated using regulatory approaches outlined in frameworks like Basel III, which may include historical loss data, business indicators, and risk control assessments. Banks are required to estimate these risks to determine the amount of capital they must hold to absorb potential losses. Operational risk exposure is a key component of a bank's total risk profile, reflecting its vulnerability to internal inefficiencies or external shocks. Managing this exposure through robust risk management systems, controls, and contingency planning is crucial to maintaining operational stability and safeguarding financial health.
Intangible assets and goodwill	IAG	Intangible assets and goodwill in banking refer to non-physical assets that represent future economic benefits but lack a tangible form. Intangible assets include intellectual property, software, trademarks, or customer relationships, while goodwill arises during mergers and acquisitions when a bank pays more for a company than the fair value of its net assets, reflecting factors like brand reputation or customer loyalty. These assets are recorded on a bank's balance sheet but differ from tangible assets in their valuation and risk. Goodwill, in particular, is subject to periodic impairment tests, as its value can decline if the acquired business underperforms. In banking, intangible assets and goodwill can enhance competitive positioning and profitability but pose challenges for risk management and regulatory compliance. During economic stress, their non-liquid nature limits their usefulness in absorbing losses, prompting regulators to impose stricter rules on their treatment when calculating capital adequacy and financial stability metrics.

Data. The data shows various financial indicators on the risk exposure of European banks, focusing on important metrics that include: Liquidity Coverage Ratio, Credit Risk-Weighted Exposure Amounts, Loans and Advances, Net Liquidity Outflow, Liquidity Buffer, Derivatives-Assets, Operational Risk Exposure Amount, Intangible Assets and Goodwill, and Total Risk Exposure Amount. Each of the measures was computed within a sample of 21 valid cases without any missing value by applying measures of central tendency, dispersion, and distribution shape. Therefore, in brief, this reflects that amongst all the indicators studied, Liquidity Coverage Ratio is relatively stable with a mean of 7,165,048 and standard deviation of 210,853. Hence, the distribution is confirmed to be almost symmetric, as median= 7,088,970 and mode = 6,809,080. It therefore follows that risk-weighted credit exposure amounts stand at a mean and a standard deviation of 2,900,322 pounds sterling and 301,312 pounds sterling, while that for loans and advances stands at a mean of 1,691,403 pounds sterling with a standard deviation of 280,149 pounds sterling. At the same time, however, the interquartile range for the two measures stands in moderation, suggesting reasonable variability that is consistent with the nature of credit risk and the business of credit granting. The liquidity buffer means 1.619 with a very small interquartile range, suggesting that banks do not show high variation in liquid reserve holdings. Further, extremes of Net Liquidity Outflow represented the mean value of 119,964 against a standard deviation of 32,091, indicating critical situations of outflow faced by certain banks. The mean of Derivatives-Assets is high, amounting to 15,249,844, but with a great standard deviation of 641,197, which means the distribution is highly dispersed. This is representative of the heterogeneity in the usage of the derivatives instruments-some banks used them more intensively for risk management or speculative purposes. Skewness and kurtosis describe the shape of the data distribution. Most metrics are negatively skewed, for example, Net Liquidity Outflow is -0.528, and Derivatives-Assets is -0.672. This indicates that most banks have values below the mean, with only a few extremely high values upward. The negative values of kurtosis, for instance, -1.427 for Derivatives-Assets, are indicative of a flat distribution relative to a normal distribution with lighter tails (Table 2).

Table 2. Summary Statistics.

Metric	Liquidity coverage ratio (%)	Credit risk-weighted exposure amounts	Loans and advances (total)	Net liquidity outflow	Liquidity buffer	Derivatives-assets	Operational risk exposure amount	Intangible assets and goodwill	Total risk exposure amount
Valid	21	21	21	21	21	21	21	21	21
Missing	0	0	0	0	0	0	0	0	0
Mode	6.809.080	2.317.150	1.552.270	111.822	1.470	14.236.396	3.389.300	817.997	8.057.240
Median	7.088.970	3.000.301	1.855.441	117.352	1.620	14.984.260	4.981.899	832.186	8.372.913
Mean	7.165.048	2.900.322	1.691.403	119.964	1.619	15.249.844	4.708.858	845.978	8.486.185
Std. Error of Mean	170.202	66.191	61.058	6.989	0.316	329.991	139.659	25.742	270.304
95% CI Mean Upper	7.261.027	3.037.484	2.028.268	133.694	1.662	15.541.716	5.000.259	857.696	8.699.227
95% CI Mean Lower	7.069.068	2.763.160	1.354.538	106.233	1.576	14.957.971	4.417.457	834.259	8.273.145
Std. Deviation	210.853	301.312	280.149	32.091	0.904	641.197	640.169	25.742	270.304
95% CI Variance Upper	59.537.059	127.626.841	39.034.659	2.075.751	0.004	264.601.175	146.825.254	154.343	96.913.578
95% CI Variance Lower	24.228.959	44.006.523	17.352.902	515.040	0.001	54.109.015	61.303.444	115.343	44.534.231
Skewness	0.161	-0.501	0.151	-0.528	0.125	-0.672	-0.432	-0.125	-0.065
Std. Error of Skewness	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501
Kurtosis	-1.253	-0.702	-1.439	-0.482	-1.199	-1.427	-0.843	-1.270	-0.924
Std. Error of Kurtosis	0.972	0.972	0.972	0.972	0.972	0.972	0.972	0.972	0.972
P-value of Shapiro-Wilk	0.416	0.062	0.046	0.094	0.048	<0.001	<0.001	0.115	<0.001
Minimum	6.809.080	2.317.150	1.552.270	111.822	1.470	14.236.396	3.389.300	817.997	8.057.240
Maximum	7.547.106	3.301.407	2.679.216	134.170	1.736	16.268.110	5.347.319	910.458	8.961.609
25th Percentile	6.990.039	2.699.168	1.580.847	114.580	1.580	14.777.772	4.622.385	832.188	8.263.082
50th Percentile	7.088.970	3.000.301	1.855.441	117.352	1.620	14.984.260	4.981.899	839.226	8.372.913
75th Percentile	7.332.674	3.131.552	2.073.637	121.392	1.706	15.891.207	5.103.007	845.090	8.689.228

Based on the standard deviation and percentiles, some important relationships among the variables that are really worth emphasizing include the closeness to one another of the mean, median, and mode for the banks' Liquidity Coverage Ratio, which points to general compliance by banks with Basel III regulatory requirements in terms of liquidity coverage. However, the wide 95% confidence interval estimate ranges from 7,069,068 to 7,261,027, which means some banks might be holding lower levels of liquidity compared to other banks, and in case of market turmoil their position may reflect a risk. Credit risk-weighted exposure amounts range from a median of 3,000,301 to a 75th percentile of 3,131,552, while directly relating to Total Risk Exposure Amount, which again confirms that credit risk is the dominant component of total banking risk. It follows from the data that the volume of loans is a key factor in overall risk exposure. The positive correlation with Total Risk Exposure Amount suggests that lending significantly increases credit risk and, thus, regulatory capital requirements.

However, despite the high mean, high variability and negative skewness in Derivatives-Assets suggest that exposure to derivatives is concentrated in a few institutions. This would, therefore, require closer monitoring of those banks that make extensive use of derivatives because of their complexity and potential systemic risk. The Amount of total risk exposure is the general measure of the risk exposure with an average of 8,486,185 and a standard deviation of 270,304. The positive dependence of the amount of total risk exposure on credit risk-weighted exposure amounts, loans and advances, and derivatives-assets follows positively, underlining that larger risks in the mentioned directions command correspondingly wider capital buffer due to their controlling nature of maintaining regulatory compliances. While the observed positive relationship with ROA points out the risk-taking activities of banks, its negative relationship with Liquidity Coverage Ratio depicts the trade-off between liquidity and risk-taking. Based on some metrics like Derivatives-Assets and Operational Risk Exposure Amount, the p-values obtained with the Shapiro-Wilk test were below 0.05, which indicates that these data are not normally distributed. That is a suggestion that some variables may be better suited to non-parametric modeling strategies. The results emphasize that efficiently balancing risk with liquidity management is a keystone for banks. Large dispersion in Liquidity Buffers and Derivatives-Assets would indicate that some institutions may benefit from greater harmonization of risk management practices. The strong correlation of Total Risk Exposure Amount with credit risk and lending activities points to the need for rigorous supervision not to allow credit expansion to dent the stability of the financial system. In summary, the data provides an overview of the risk exposure determinants in European banks, the challenges, and opportunities as per the regulatory and risk management perspective. Its analysis therefore carries a number of valuable messages regarding how the resilience and sustainability of the banking sector can be improved.

4. Econometric Models

We have estimated the following equation with OLS, Heteroscedasticity-corrected and ARMAX:

$$\boldsymbol{TREA_t = a_1 + b_1(LCR)_t + b_2(CRWEA)_t + b_3(LA)_t + b_4(NLO)_t + b_5(LB)_t + b_6(DA)_t + b_7(OREA)_t + b_8(IAG)_t}$$

t=[Q2 2019; Q2 2024].

The results are shows in the following Table 3.

Table 3. Results of the econometric models.

	Heteroscedasticity-corrected, using observations 2019:2-2024:2 (T = 21)			ARMAX, using observations 2019:2-2024:2 (T = 21)			OLS, using observations 2019:2-2024:2 (T = 21)		
	Coefficient	Std. Error	t-ratio	Coefficient	Std. Error	z	Coefficient	Std. Error	t-ratio
Coefficient	13808.3***	2693.70	5.12	13549.2***	3358.88	4.034	13549.2***	3358.88	4.03
LCR	-7944.85***	1542.50	-5.15	-7820.80***	1943.62	-4.024	-7820.80***	1943.62	−4.02
CRWEA	0.89***	0.07	11.45	0.89***	0.102506	8.714	0.89***	0.10	8.71
LA	0.13***	0.02	4.77	0.12***	0.0425958	2.936	0.12**	0.04	2.93
NLO	-4.46***	0.88	-5.04	-4.38***	1.15506	-3.797	-4.38***	1.15	-3.79
LB	2.60***	0.52	4.99	2.57***	0.671751	3.837	2.57***	0.67	3.83
DA	0.09***	0.01	6.13	0.09***	0.0283302	3.455	0.09***	0.02	3.45
OREA	2.53***	0.34	7.33	2.50***	0.478282	5.231	2.50***	0.47	5.23
IAG	-21.18***	3.43	-6.16	-20.24***	4.50319	-4.495	-20.24***	4.50	-4.49
Statistics	Sum squared resid		21.71	Mean dependent var		8486.18	Mean dependent var		8486.18
	R-squared		0.99	Mean of innovations		0.00	Sum squared resid		3521.10

	F(8, 12)	2013.18	R-squared	0.99	R-squared	0.99
	Log-likelihood	-30.14	Log-likelihood	-83.57	F(8, 12)	621.01
	Schwarz criterion	87.69	Schwarz criterion	197.60	Log-likelihood	-83.57
	rho	-0.24	S.D. dependent var	270.30	Schwarz criterion	194.55
	S.E. of regression	1.34	S.D. of innovations	17.12	rho	-0.32
	Adjusted R-squared	0.99	Adjusted R-squared	0.99	S.D. dependent var	270.30
	P-value(F)	1.43e-17	Akaike criterion	187.15	S.E. of regression	17.12
	Akaike criterion	78.29	Hannan-Quinn	189.42	Adjusted R-squared	0.99
	Hannan-Quinn	80.33			P-value(F)	1.63e-14
	Durbin-Watson	2.31			Akaike criterion	185.15
					Hannan-Quinn	187.19
					Durbin-Watson	2.50

Notes: *** p-value < 0.01; ** p-value < 0.05; * p-value < 0.10.

The negative relationship between total risk exposure amount and liquidity coverage ratio (%). Driven by the needed trade-offs between both risk-taking and regulatory demands on liquidity, the fundamental relationship between total risk exposure and the LCR is negative for European banks. Banks that have higher total risk exposure load up on activities such as extensive credit granting, investing in riskier assets, or derivatives trading. Such modes require larger buffers of capital to absorb potential losses. The above activities may reduce either the ability or motivation of the banks to retain a high level of high-quality liquid assets, which consist of the substantive core basis within which LCR has been estimated. In others, the higher the risk-the more important would the capital sufficiency over liquid reserves become-hence, decreasing the LCR position. Market conditions and regulatory pressures simply exacerbate this inverse relationship. European banking regulations, such as Basel III, in conjunction with the liquidity requirements, place strict capital demands on banks, which force them to make strategic tradeoffs. Institutions with higher risk profiles may view the large liquidity reserves as a drag on profitability, hence further increasing the incentive to minimize their HQLA holdings. During periods of market stress, riskier institutions also generally face higher funding costs, constraining their ability to maintain liquidity buffers. Thus, what the relationship reflects negatively mirrors the structural and current regulatory dynamics into which banking in particular is plunged, which regards the difficult effort of its counterbalancing at risk through enhanced liquidity resilience (Simion et al., 2024; Baros et al., 2023; Mihai, 2023).

The positive relationship between Total risk exposure amount and credit risk-weighted exposure amounts. The positive relationship between total risk exposure amount and credit risk-weighted exposure amounts is among the most current issues in the field of macro-prudential and banking supervision in Europe. In contrast to the total risk exposure amount, which displays the overall risk a bank is exposed to regarding credit, market, and operational risks, credit risk-weighted exposure amounts deal with credit-related risks weighted by the risk weights linked to the different asset types. This relationship is thus inherent in European regulatory frameworks, such as those provided by the Basel Accords, which aim at promoting prudent credit risk management. Generally speaking, as the credit risk-weighted exposure amount of a bank increases, the total risk exposure amount increases proportionally, since riskier assets require higher capital reserves to ensure financial stability. This is a very important linkage for supervisors, whereby, through these metrics, they keep track of the stability of the banking system and try to avoid systemic risks. Most noticeably, it reveals the goodness and efficiency of such a risk-weighting framework in that this approach neither undermines the value of credit risks nor allows any over-capitalization of credit exposures. Thus, good risk management policy can be applied, reinforcing European banking system stability. This, of course, protects the whole European banking sector from stress situations in respect to financial ability and maintains the required financial stability in the general economy (Milojević and Redžepagić, 2021; Dinu and Bunea, 2022; Leogrande et al., 2023).

The positive relationship between total risk exposure amount and loans and advances. This level of total risk exposure and the amount of loans and advances represent a very important area of analysis from a macro-prudential perspective of regulation and supervision in the European banking context. Total risk exposure gives the broad indication of the general vulnerability of the bank from several risks: credit, market, and operational. Loans and advances are one of the key assets in which credit risk is inherently built up in every credit transaction. In a macro-prudential framework, an increase in the amount of credit extended normally corresponds to increasing the amount related to total risk exposure. In such a respect, there goes a direct relation between credit extension and systemic risk. While banks extend more credit, not only do they enhance their exposures towards borrowers' defaults, but also multiply their contribution to overall risk to the entire financial system. Supervisory authorities monitor this relationship closely, given that overly rapid credit growth may outpace the capacity of risk management or the resilience of the wider financial system. This is an important dynamic to consider in Europe, given the interconnected nature of its banking institutions and its emphasis on financial stability. In this way, regulators can draw conclusions about how loans relate to total risk exposure and, by extension, develop specific interventions-such as capital buffers-to reduce systemic vulnerabilities while still accommodating credit growth in a sustainable way (Thapa and Sejuwal, 2023).

The negative relationship between total risk exposure amount and net liquidity outflow. This negative relation between total risk exposure and net liquidity outflow in the context of macro-prudential regulation and banking supervision of European banks underlines a dynamic interaction between risk management and liquidity stability. The banks with higher total risk exposure are usually highly regulated and also face higher capital requirements that forbid them from easily engaging in activities that increase the liquidity outflows. The latter can partly be explained by higher risk exposure indicative of vulnerabilities, which would then make supervisors pay more attention to preserving liquidity as a means to make banks more shock resistant. Conversely, banks with lower net liquidity outflows tend to have stronger balance sheet resilience. They are the ones able to absorb market stress without being forced to prematurely liquidate their assets, something very important in bad times. This relationship is magnified by the European regulatory environment that at least in spirit encourages banks to keep stable funding profiles and strong liquidity buffers, thus reducing scope for excessive risk-taking. The underlying negative relationship, important in promoting financial stability and objectives of lowered systemic risk, means disincentives exist for heightened risk profiles to impound liquidity, in such a way that resilience banking can be created with supervisory priorities in sight (Huang et al., 2023; Baros et al., 2023; Simion, et al., 2024).

The positive relationship between total risk exposure amount and liquidity buffer. The fact that there is a positive nexus underlying total risk exposure amount and the liquidity buffer is an assurance of prudent risk management and regulatory oversight within the macro-prudential framework in European banking. It thus follows that banks with higher total risk exposures are by nature more exposed to market shock and adverse economic conditions. In mitigating these vulnerabilities, their regulators do encourage the maintenance of strong liquidity buffers in such institutions. These buffers must necessarily be held by banks to enable them to meet their short-term obligations in periods of financial stress and protect not only the individual institution but also the wider financial system. This relation reinforces financial stability from the macro-prudential point of view. That would be very important because having more highly risk-exposed banks maintain higher liquidity reserves adds to the overall resilience of the banking sector and reduces the vulnerability of the whole banking system from systemic crises. The second point is that aligning liquidity with risk has as its collateral effect a tendency to make the institutions internalize the possible costs of their risk-taking behavior, hence profitability with safety. This relationship underlines, in European banking, the need for risk management to go hand in hand with liquidity planning, as regulatory frameworks focus more on containing risks and enhancing stability. Since then, and even now, banks happen to remain in the threshold of supervisory expectations while further working their stamina to deal better with uncertainties related to sustaining the confidence in the financial system (Broto et al., 2022; Simion et al., 2024).

The positive relationship between total risk exposure amount and derivatives-assets. The relationship between total risk exposure and the use of derivatives assets in European banking is complex, especially with regard to macro-prudential oversight and banking supervision. Derivatives are financial instruments that play a dual role. On one hand, they enable banks to hedge risks such as changes in interest rates or fluctuations in currency values, thus decreasing particular risk exposures. The riskiness and complexity of derivatives is at one and the same time their leverage-another factor leading to an inclination towards raising the aggregate level of risk on a bank's balance sheet. Under the macroprudential heading, this too means that their use is related positively to general exposure to risk in that large holders of derivatives could be engaging in activities that especially enhance the interdependence of financial systems. Interconnectedness, essential for liquidity and efficiency, is, at the same time, conducive to systemic vulnerability when economic conditions are adverse. It is in consideration of this fact that the supervisory frameworks in Europe emphasize two different aspects of derivatives: as tools to handle risk but at the same time sources of rising exposure through, among other aspects, counterparty risk or valuation uncertainty. In all, while derivatives allow for sophisticated strategies of risk management, the higher overall risk exposure linked to them underlines the need for sound oversight so that their benefits do not worsen financial stability in the European banking sector (Miloș and Miloș, 2022; Venanzi, 2020).

The positive relationship between total risk exposure amount and operational risk exposure amount. Within the framework of the macro-prudential policy and supervision of European banking, there is a positive link between the total risk and the operational risk exposure. This can be considered as that kind of relationship which shows the peculiar nature of modern banking, where the overall higher the risk appetite, the greater the vulnerability to operational risks. The larger the bank and wider the range of diversified and complex financial activities, including trading, lending, and global market operations, the greater the total risk exposure. At the same time, the very complexity and diversity of these operations increases the prospect of operational failure, including everything from systems breakdowns to compliance failures. This means that the operational risk of a bank also is strongly related to the overall risk profile since increased market, credits, or liquidity risk exposure requires more complex internal procedures and controls. Hereby, the control system would be also a source of weakness, especially for large, systemically important institutions. Given the tight and demanding nature of the regulatory requirements, European banks find themselves under huge pressure trying to balance their decisions between taking high risks and exercising enough operation control-the greater the riskier. This positive relationship suggests that supervisors should embed operational risk assessments within comprehensive risk-monitoring frameworks. Regulators who consider the means through which operational vulnerabilities rise with total exposures can construct richer tools for promoting resilience and engendering stability in the European banking system (Abrampva, 2021; Krasnova et al., 2022).

The negative relationship between total risk exposure amount and intangible assets and goodwill. This negative relation of the total risk exposure of goodwill and other intangible assets to their value just aptly epitomizes how these kinds of asset are intrinsically fragile. The goodwill and other intangible assets are considered not tangible. Normally, in European banking regulation concerning macro-supervision of banking, as far as most financial statements are subject to perception from market participants about valuation, one will usually find that they do not have almost all the time the liquidity and solidity of their tangibles. The implication is therefore that they magnify banks' weaknesses, especially during economic recessions when risk exposures inflate. Due to the volatility of intangibles that may mask the true condition of a bank, supervisory arrangements worldwide and in particular in Europe would focus on prudent considerations. Under the rising common exposure to the credit, market and operational risks all banks with big sums of goodwill along with intangible assets attract greater consideration. This is in line with correspondingly reduced loss-absorption capacity and quality as collateral. Besides, goodwill can be sharply written down in the event of an underperformance of the underlying acquisitions; further increasing the capital shortfalls undermining confidence in the markets. That dynamic, in a macroprudential perspective, constitutes a need for regulatory policy in regard to discounting the weight that intangible assets have in assessments of capital adequacy. The bottom line is that systemic stability should not be compromised due to overdependence on volatile asset classes non-recoverable within the risk management framework and building resilience in banking institutions. (Wu and Lai, 2020; Elkemali, 2024; Kimouche, 2022).

5. Machine Learning Regression

The analyzed model is also tested through the application of the following machine learning algorithms namely: k-Nearest Neighbors Regression, Random Forest Regression, and Support Vector Machine Regression. The performances of the algorithms are indicated in the Table 4 below:

Table 4. Machine Learning Regressions' results.

Model Performance Metrics	K-Nearest Neighbors	Random Forest	Support Vector Machine
MSE	5259	13940	3184
MSE(scaled)	0,013	0,046	0,069
RMSE	72,52	118,068	56,427
MAE / MAD	66,726	97,266	51,17
MAPE	0,79%	1,17%	0,61%
R^2	0,982	0,939	0,911

In order to effectively apply a sorting rule we proceed to the normalization of the data through the application of the following formulas:

- $\frac{MaxMetric - Metric_i}{MaxMetric - MinMetric}$ **:** for metrics where lower values are better such as in the case of MSE, RMSE, MAE and MAPE;
- $\frac{Metric_i - Min\ Metric}{MaxMetric - MinMetric}$: for metrics where higher values are better**;**

Where Max Metric is the maximum value of the metric across all models, Min Metric is the minimum value of the metric across all models, $Metric_i$ is the value of the metric for model i (Table 5).

Table 5. Normalized results.

Algorithm	Acronym	MSE	MSE_scaled	RMSE	MAE	MAPE	R^2

K-Nearest Neighbors	KNN	0.80	1.0	0.73	0.66	0.678	1.0
Random Forest	RF	0.0	0.41	0.0	0.0	0.0	0.39
Support Vector Machine	SVM	1.0	0.0	1.0	1.0	1.0	0.0

Considering equal weights for all metrics:

$$w_{MSE} = w_{RMSE} = w_{MAE} = w_{MAPE} = w_{R^2}=0.2$$

We apply the following sorting role to compute the score:

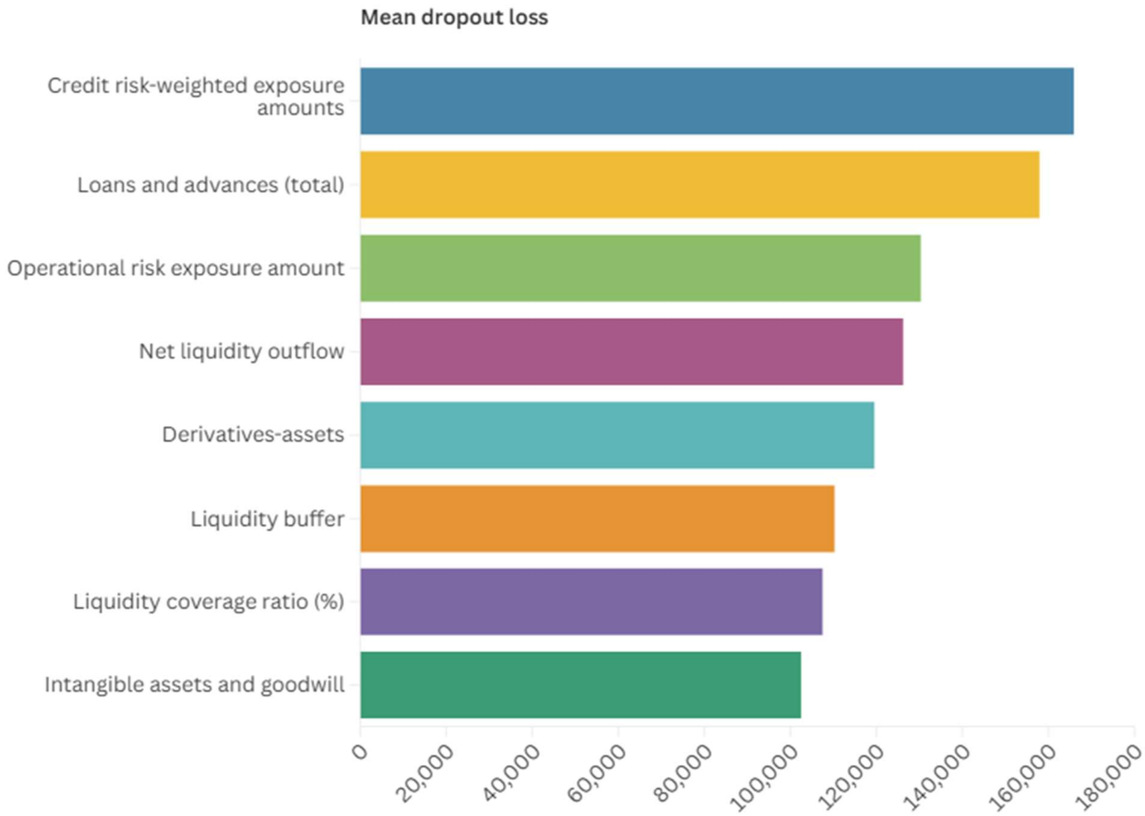
$$Score_i = w_{MSE}MSE + w_{RMSE}RMSE + w_{MAE}MAE + w_{MAPE}MAPE + w_{R^2}R^2$$

Applying the rule we obtain the following result: $Score_{SVM} = 0.8 > Score_{RF} = 0.078 > Score_{RF} = 0.77$. So we find that the best algorithm is the SVM.

Application of the Support Vector Machine in the intepretation of the model. Results using the Support Vector Machine model on the Total Amount of Exposure of Risk will add important insights both on the performance and reliability of the model and into the financial metrics inside the estimation process. The analysis encompasses a broad range of critical financial variables such as credit risk-weighted exposure amount, loans and advances (total), operational risk exposure amount, net liquidity outflow, derivatives-assets, liquidity buffer, liquidity coverage ratio, and intangible assets and goodwill. Each one of these has a different role in assessing total risk exposure; their contributions have to be varied for a fine understanding of financial stability and the institution's risk profile. Among all the analyzed metrics, the highest reading was Credit Risk-Weighted Exposure Amounts at 165.871; this was credit risk with the highest constituent value in Total Risk Exposure Amount. Typically, credit risk exposure arises out of loans and advances together with other related credit instruments to a bank customer; such indicates the likely loss because of borrower defaults. This high value for the metric underlines how efficiently credit risk management is undertaken and the degree to which this contributes to the overall risk exposure of the institution. This is followed closely by the metric of Loans and Advances standing at 157.891, representing the sum total amount of money involved in the institution's lending activity, being part and parcel of its core business. Loans and advances increase credit risk directly, and therefore, their evaluation is of essence in understanding the wider risk exposure. The strength of the model in accommodating this variable effectively indicates that it accounts for one of the main causes of financial risk. Another significant contributor is the Operational Risk Exposure Amount, which has a value of 130.296. Operational risk is the possibility of loss resulting from some sort of inadequate or failed internal process, system, and human factor, or external events. This metric shows that strong operational controls and good risk management practices are very crucial in mitigating unexpected disruptions that could affect the financial health of the institution adversely. The Net Liquidity Outflow, measured at 126.191, is a very important indicator of the institution's liquidity position. The cash flow metric represents net cash outflow that is expected to occur under the stressed scenario-an instance where sudden or severe demands are made for liquidity resources. Thus, this metric carries a relatively high value, important in the context of the risk management framework of any institution. When adequately projected, this variable will provide an important insight to the SVM model about the degree of resistance or resilience of any institution against potential liquidity stressors.

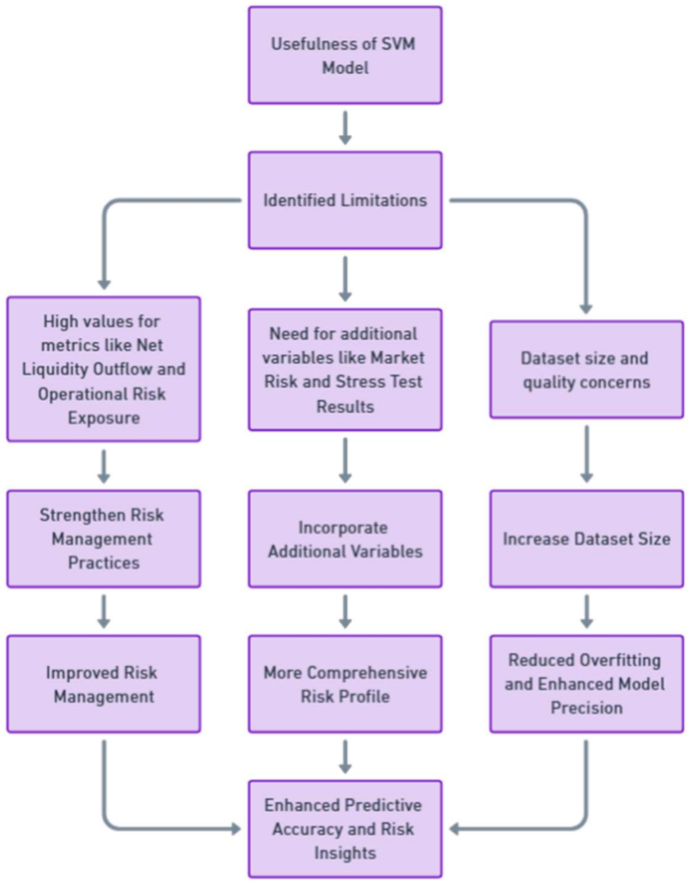
The Derivative-Asset Ratio of 119.499 throws light upon the role played by derivatives within the institution's portfolio. Derivatives are thus used for either hedging purposes or speculative aims and can generate considerable risk as a result of their complexity because of large, potential losses through adverse market conditions. While this is not a high value compared with others, the implication is that a great deal of care is called for when managing Derivatives Exposure since these add to financial risks. Liquidity Buffer : This is the pool of highly liquid assets maintained by any institution to counteract probable cash outflow: 110.254. In developing economies and systems, an adequate enough level of liquidity buffer will guarantee a fight against temporary liquidity shocks. This metric helps complement the previous one, and together they give the full view about the institution's liquidity risk profile. Indeed, the importance of this variable being incorporated into the model is established while determining the preparedness of this institution for every liquidity crisis. Liquidity Coverage Ratio: 107.466% This regulatory metric compares liquidity buffer to estimated net cash outflows over a 30-day stress scenario. LCR over 100% is considered positive for liquidity management, meaning the institution has enough high-quality liquid assets to meet its net cash outflows. Including this metric into the model will illustrate that the proposed SVM model follows the regulatory requirements and will be useful for assessing compliance with liquidity standards. The amount for Intangible Assets and Goodwill stands at 102.468. These would include intangible assets: brand reputation, intellectual property, and customer relationships of the institution. While valuable, these assets are less liquid and cannot readily be transformed into cash in periods of financial stress. Their inclusion here underlines their subsidiary role in overall risk exposure, given that they are less directly linked with the institution's short-term liquidity and solvency. The mean dropout loss is the RMSE that gives a quantitative measure of the predictive performance of the developed SVM model. The metric was computed 50 times by repeated random sub-sampling to check the model for stability and accuracy under different conditions. The use of 50 permutations shows that Mean Dropout Loss considers the model variability for the estimation of its performance in a robust way. A small RMSE signals that the model achieved an excellent degree of accuracy in the prediction of Total Risk Exposure Amount, which can be interpreted to mean its average deviation between predicted and actual values was at a minimum. Inclusion of this metric highlights the reliability of the SVM model as a tool for risk estimation. Looking at the overall results, the percentage variation is noted in the financial metrics analyzed, whereby the amount of credit risk exposure dominates the risk profile, followed by loans and advances, then operational risk on the high end. These metrics obviously represent the main components of the Total Risk Exposure Amount, the correct estimate being therefore fundamental for good risk management. The metrics of Net Liquidity Outflow and Liquidity buffer complete this work to provide comprehensive insight into the Institution's liquidity position or short-term resilience in the perspective of liquidity stresses. Less prominent are derivatives-assets, which will nonetheless remain an important consideration given the huge losses they could cause under adverse market conditions. Intangible assets and good will play a more minor role in overall risk exposure because of their essentially non-liquid nature (Figure 1).

Figure 1. Mean Dropout Loss.



Limitations of the analysis. The model has been useful as a risk management tool due to the ability of the SVM model to integrate these diverse metrics and make good predictions. The results also show areas where improvement is required. For example, high values for some metrics, such as net liquidity outflow and operational risk exposure, indicate that the institution should strengthen its risk management practices in respect of these areas. Besides, further refinements of the model could be obtained by adding other relevant variables, such as market risk exposures or stress test results, in order to get a more complete view of the institution's risk profile. Another issue that might be of concern is the size and quality of the dataset. However, while the use of 50 permutations gives an extremely robust measure of the model's performance, increasing the size of the dataset would be a further improvement in precision and generalizing of the model. This could have been improved with a much larger dataset so that it better generalizes a broader range of variabilities in input data, consequently reducing overfitting and increasing predictive performance. Other questions these results raise are related to the importance of the variables considered within the analysis. Feature importance analysis can be really enlightening in showing which of these variables influences more in the amount of Total Risk Exposure. This would help underpin risk management prioritization efforts through concentrating resources on the most relevant drivers of financial risk. The performance of the SVM model is very good for the estimation of Total Risk Exposure Amount, which uses a wide range of financial metrics to provide an accurate and reliable prediction. Mean Dropout Loss is computed as the RMSE over 50 permutations and is actually a robust indicator of performance for this model, underlining its stability and accuracy. Emphasized in the analysis are credit risk, loans and advances, and operational risk management, since these metrics proportionally dominate overall risk. Such an understanding is further complemented by liquidity metrics on net liquidity outflow, liquidity buffer, and liquidity coverage ratio, thereby providing an insight into the resilience of the institution to liquidity stress (Figure 2).

Figure 2. Limitations of SVM.



6. Machine Learning clustering to evaluate the total exposure toward government among european countries

In this section we analyze the characteristics of European countries in terms of total exposure to general governments. To analyze the characteristics of different countries we compare 3 clusterization models in order to identify the optimal number of clusters. The cluster analysis is used to understand whether there are significant differences between European countries in terms of exposure of the banking system to national governments. We have applied the following clustering algorithm to find the optimal number of clusters. The statistical results of the algorithms are showed in the following Table 6.

Table 6. Results of machine learning algorithms for clustering.

Model Performance Metrics	Fuzzy c-Means		Hierarchical		Model Based	
	Value	Normalized	Value	Normalized	Value	Normalized
Maximum diameter	4.217	0.10	3.176	0.03	2.103	0.03
Minimum separation	0.52	0.01	0.829	0.006	0.022	0.0001
Pearson's γ	0.69	0.01	0.86	0.006	0.579	0.009
Dunn index	0.123	0.0	0.261	0.0	0.01	0.0
Entropy	0.598	0.01	0.487	0.002	0.917	0.01
Calinski-Harabasz index	39.328	1.0	88.299	1.0	62.85	1.0

To find the best clustering algorithm we choose to use the following formula:

$$S_i = \sum_{j=1}^{6} w_j Metric_{i,j}$$

Where i is the algorihtm and j the metric, w_j is the weight for metric j and $Metric_{i,j}$ is the value of metric j for the algorithm i. Applying the formula we find the following results: Fuzzy c-Means =0.125>Model Based=0.1088>Hierarchical 0.1086.

The data shown below outlines total exposure to governments by two different groupings of European countries. For the purpose of this exercise, we will call these clusters C1 and C2; they are differentiated by their respective member states and by the mean amount of exposure in millions of euros. Their contribution to the government debt exposure is highly unequal, reflecting the difference in the economic scale, fiscal policies, and financial ecosystem of the member countries. Cluster C1 comprises 18 European countries: Belgium, Bulgaria, Germany, Estonia, Ireland, Greece, Croatia, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Austria, Portugal, Slovenia, Slovakia, and Finland. These countries give a good representative of the diversity in economies found within the European Union, mostly being smaller and with relatively low amounts of government debt issuance in respect to their GDP. The mean total exposure amounts to € 43,433.18 million for C1, describing modest amounts of exposure given the larger economies grouped within Cluster C2. Indeed, the overall relative low exposure that characterizes the C1 Group can be identified with several favorable factors: rather prudent fiscal policy reducing government borrowings, conservative fiscal policy behavior, such as countries with Finland or Luxembourg, normally holding relatively low national debts-to-GDP ratio that reduces the impetus to excessively issue large quantum of government securities. Notably, the smaller economic scale of many C1 countries inherently keeps their overall capacity for borrowing rather low, as the domestic financial systems of these countries are not as large compared to bigger economies. As such, countries with relatively small economies like Malta, Latvia, and Estonia require less borrowing to maintain investments in the public sector and social programs. Besides, heterogeneity in the economic performance of members within C1 argues for variable exposure of the member states to risks. While the likes of Germany and Austria are larger and better capitalized, which contributes to this share in collective exposure, history has more often placed fiscal challenges on the likes of Greece and Portugal, so a higher relative risk is possible. In summary, cluster mean exposure remains at a moderate level and reflects a balanced and less severely concentrated risk profile compared to the bigger economies in C2. By contrast, Cluster C2 includes three of the largest economies in the European Union: Italy, France, and Spain. For C2, the mean total exposure is €460,619.20 million, over ten times the mean exposure in C1. That underlines how huge these economies are and their pivotal positions in the European financial ecosystem. These economies are large and thus have high borrowing needs, which explains the high level of exposure to government debt. A number of reasons explain the high level of exposure in C2.

Firstly, the size of the economies in Italy, France, and Spain requires heavy spending by the government in order to maintain its infrastructure, public services, and social programs. This is usually financed by heavy government borrowing, thus increasing the degree of exposure. The second reason is that such countries have generally higher levels of public debt, therefore increasing their borrowing needs. For example, Italy has one of the highest debt-to-GDP ratios in the EU, driven by decades of fiscal imbalances and economic challenges (Proença et al., 2022; Moroz, 2021; László, 2022).

More precisely, Italy, France, and Spain are the hubs of European financial markets; they could hence be regarded as fundamental participants in the international debt market. This also makes them susceptible to a great deal of exposure from both domestic and international investors, in addition to their already highly exposed situation. France is an issuer of sovereign bonds while Spain has also become more attractive to investors of late due to the economic revival there. The role of the Italian economy and state in every crucial decision in the EU means that this value of state debt on offer will definitely act further as a guide for investors worldwide. This means that the astonishing value of the exposure considered for C1 to C2 can roughly be magnified by one order of 10.6 magnitude. Immediately it, focuses on the differentials of fiscal policy and the current economic scenario between the two clusters themselves, with one cluster comprising relatively small-sized economies and which are essentially conservative in terms of borrowing habits as also, members C2 comprise those countries which comprise big sized economic block and an unprecedented hunger for credit appetite comprising huge financial market. Such a comparison underlines the heterogeneity that characterizes the European Union's reality, where nations of very different economic magnitudes coexist and contribute to the general financial stability of the region. In terms of risk management, such differences are far from irrelevant. They were considered to probably denote not necessarily lesser risks but definitely low absolute risk factors for investors with respect to generally less issuance in government debt issued by those particular countries. A moderate degree of exposition could attest to low propensity from the country toward systemic risks as far as its own system was concerned against the European area in an aggregate manner but risks stemming from single individual countries such as that of Greece and Portugal within the set C1 will differ radically, for example. For instance, Greece has had its fair share of fiscal crises that have plunged the country into periods of high risk for investors. C2 countries involve a larger degree of systemic risk due to the extent of exposure. Italy, France, and Spain are significant players in European and global financial markets, and any sharp turbulence in the economy of these countries would have more far-reaching implications. For example, a fiscal crisis in Italy, given the level of its indebtedness, can spread to the Eurozone and have consequences for both financial markets and investor confidence. On the other hand, any disruption in France and Spain will consequently have wide reverberations into the overall monetary stability of the whole European Union. Analysis of C1 and C2 underlines also the importance of knowing about the drivers behind the exposure in government debt. These insights are, therefore, going to be important for policymakers in formulating their strategies to contain fiscal risks and promote economic stability. In this regard, smaller economies within C1 might have to adopt continued fiscal prudence and efforts at attracting sustainable investment. Larger economies in the C2 class could focus on reducing debt levels and strengthening their fiscal frameworks to enhance their resilience to exogenous shocks. This leads to the inference that the aggregate exposure to government entities has a clear gulf between the two clusters of European countries. The first cluster represented the relatively smaller economies that have modest financing requirements with conservative fiscal records with an average exposure of € 43,433.18 million. While C2, at €460,619.20 million of average exposure, would show the fiscal scale and the related borrowing requirement for three of the largest economies of the EU, the contrast between these two clusters underlines heterogeneity in the European Union and allows observing the different fiscal positions of its members (Nikolaieva and Yakubovskiy, 2023; Burriel et al., 2022; Linciano et al., 2021).

7. Policy Implications

The understanding of TREA determinants in European banking is of paramount importance for policy implications that aim at ensuring financial stability, risk management, and full compliance with regulatory frameworks like Basel III. The critical factors related to the determination of TREA are those that should be addressed by policymakers, regulators, and financial institutions as a measure of mitigating systemic risks, strengthening financial resilience, and aligning banking practices with the broader economic objectives. Strong regulation is crucial for the effective management of TREA. Refinement in the capital adequacy rules is called for in a way that the exposures can be appropriately weighted correctly for credit risk. Dynamic risk weights, applied by regulators, enable one to avoid underestimation of risk and ensure that reserved capital corresponds to the real risk profile of banks at any time. Meanwhile, the liquidity requirements need to be enhanced in order to break the inverted relationship between TREA and the liquidity coverage ratio. Highly risky banks usually compromise their liquidity buffers to attain profitability that may undermine financial stability. The enhancement of stress-testing frameworks, together with the imposition of more strict liquidity reporting requirements, is necessary in ensuring that banks hold an adequate reserve of high-quality liquid assets. The trade-offs between risk-taking and liquidity management underline the urgent need for such strategies that concertedly take care of profitability as much as resilience. For example, derivatives are an important hedging vehicle for financial risk, but because of that very complexity, leverage increases in exposure. Policymakers need to shift the attention of their endeavors toward more proper supervision of derivative trading, the goal being the assurance that those instruments at the least serve appropriate uses. Of course, by so doing, losses and possible reputational associated risks will effectively be minimized. In fact, also crucial for compelling reasons is how the operational hazard-a major facilitator of the TREA-is so controlled internally along with cybersecurity frameworks. Moreover, the prudential prescription needs to be framed in a manner so as to incentivize banks to invest in state-of-the-art risk management systems with a view to bringing down the risk of operational failure. The second important areas are lending practices because there exists a high association between TREA and loans and advances. That is an issue of huge concern also because very rapid credit growth-even though conducing to economic growth-raises systemic risk substantially. During the period of boom, there are required regulatory measures that avoid excessively fast credit growth; for example, countercyclical capital buffers. Besides, it is desirable that policies on lending would better take into consideration macroeconomic positions and thus foster prudence during expansion and flexibility on the part of regulators in recession. The promotion of diversification of portfolios reduces risks associated with high loan concentrations and enhances financial stability (Budnik et al., 2021; Milojević and Redžepagić, 2021; Gehrig and Iannino, 2021).

Liquidity management remains at the heart of banking sector resilience. The positive relation of TREA with liquidity buffers suggests that for a bank with a high risk profile, the need is felt for sufficiently strong liquidity buffers. Policies should be put in place to ensure that the banks hold sufficient liquidity to absorb shocks in the markets and meet short-run obligations during any period of financial distress. Also, the negative relation of TREA with net liquidity outflow suggests that what is important about funding profiles is their stability. Regulators should ensure that banks contingency plan for liquidity shocks to prevent unexpected cash flow pressures from destabilizing the operations of banks. Intangible assets, especially goodwill pose peculiar problems in the context of TREA. These, per-se, are volatile and absorb minimal loss. These provide for the financial vulnerability at times of downturns. The policymaker needs to implement conservative valuation for such intangible assets and, to the extent possible exclude such capital base calculation. Testing for impairment, therefore, has to be instituted from time to time to correctly value the intangible assets in a proper way reflective of market value so as not to camouflage the underlying risks. Heterogeneity in government debt exposure across European countries introduces another dimension into the discussion of often-issued policies. For the smaller economies, their relatively lower credit exposures imply fiscal prudence and challenges in investment sustainability. Strong initiatives for larger peers like Italy, France, and Spain toward public debt reduction are called for, supported by an improving fiscal framework to cushion the risk of higher borrowing demand. This will eventually add up and translate into a higher contributing factor for system-wide vulnerability, facilitating a more robustly stable European banking system at large. The salient points in this regard refer to implications for policymaker sides: namely, advanced analytics with state-of-the-art technologies like machine learning methodologies, giving an added value in analyzing driver insights that constitute TREA and allowing robust, more precise assessments in risk gauges. Precisely, the used machine learning methodologies are Support Vector Machines that have considerable potential for insight into the drivers of TREA and, by extension, can attain high accuracy for risk assessments. In addition, policy makers can offer incentives so that the integration of AI-based tools may support the execution of real-time risk analysis that improves banks' decisions regarding better capital allocation, more robust observance to regulatory prescriptions, and higher overall resilience. To this effect, investments in technological innovations would, therefore, enhance the banks' capabilities for mastering increasing complexities of risk management in a dynamic and changing financial environment. Based on this view, the logical consequence of this is that determinants of TREA are requiring a multi-dimensional policy approach: rightly balancing regulatory rigor with flexibility and prudential risks by leveraging on technological advancements. Indeed, with focused emphasis on capital adequacy, liquidity management, prudent lending, and operational resilience, the regulators in Europe will be in a position to work out a practicable long-term regime for risk management. It would, therefore, be relevant not just in terms of individual institution stability but also in relation to creating the resilience of the overall European Financial System (El-Chaarani et al., 2023; Simion et al., 2024; Danisman et al., 2021).

8. Conclusions

The research into the factors of influence on the Total Exposure Amount of Risk in the European banking system creates a holistic outlook on the risk dynamics, with concomitant regulatory compliance. From the results derived in this research, one can emphasize that TREA forms the baseline for the Basel III framework, especially in its key role in the capital adequacy calculation of banks and systemic stability. Key insights are that TREA interacts dynamically with a range of financial and operational metrics, including credit risk-weighted exposure amounts, loans and advances, liquidity coverage ratios, liquidity buffers, derivatives-assets, operational risk exposure amounts, and intangible assets and goodwill. These show the opportunities and challenges in balancing risk-taking, liquidity management, and compliance with prudential regulations. The following research will also be able to bring out in further detail this negative relationship between TREA and LCR: the trade-offs that a bank would have to make between taking more risk and managing its liquidity. Banks with higher risk exposures are often constrained to maintain adequate liquidity buffers, reflecting prioritization of profitability over liquidity resilience. This negative relationship exposes the pressure that regulatory agencies place on banks to strive for an optimized capital buffer, while maintaining a level that ensures liquidity levels are not causing their operational handicaps. While, on the other hand, one could see that the positive relationship of TREA and CRWEA denotes how strong the Basel framework was and how inescapable and directly, or better put, obvious is the relation of the insufficiency degree to the entity's credit risk by the very adequacy degree. This point touches upon and tends to underscore or prove an obvious efficiency effect, and how schemes-like credit-risk weightings linking adequately to logical hazard profiles, or schemes which strengthened and enhanced European Banking System Stability, or EBUA. This is further evidenced by the positive relationship between TREA and LA, hence further solidifying systemic implications with respect to credit expansion. On the whole, high credit growth rates may build systemic vulnerability during times when countercyclical measures are significantly necessary. In other words, from a positive linkage, the build-up of liquidity buffers from TREA into LB is an important feature that could be put also under risk management.

Therefore, for such a reason, it has to follow that banking system when there's an exposition which can come out. The findings agreed with the regulatory objective to position banks in such a way that they are able to absorb the shocks of any kind without being impaired in operating it. It also brings to light the complicated dynamics of the derivatives-assets and their good and positive relationship with TREA-speaking volumes about the twin roles of derivatives in hedging risks away and being sources of systemic vulnerability. It allows sophisticated ways in which one can handle one's risks but once more contains everything that is innate in calling rigid oversight since effects and leveraging may aggregate unduly to critical risks. It also identifies that the operational risk exposure is one of the pivotal agents in magnifying the overall risk and that, hence, stringent internal controls and contingency planning are required to reduce the associated vulnerabilities of complex banking operations. The negative relation between TREA and IAG reflects that the intangible assets are fragile to absorb the losses during the economic downturns. The results of this are supportive evidence showing that conservative valuation intangible asset regulatory treatments for arriving at capital requirements are one way in which the bank's risk profiles show greater accuracy. The paper applies some high-level econometrics and machine learning models in analyzing the TREA determinants in a methodological manner; for instance, the use of the support vector machines. With its robustness in integrating various financial metrics with high accuracy, SVM is a very promising AI-driven tool to consider for upgrading risk assessment and regulatory compliance. Application of machine learning methodologies will enable banking and regulating firms to get insight into the dynamics of the risk faster, real time, and well on their way toward proactive risk management and policy intervention. Supervision with respect to derivatives trading and operational risk management should be further enhanced with a view to containing systemic vulnerabilities. Also, policies that encourage prudent credit growth and portfolio diversification by loans would contribute to the deduction of systemic risks with economic growth maintained. The second point is quite incisive because it relates to technological innovation in the role of investment in risk management. The banks apply AI-enabled enabling tools, thereby making them masters of the complex contemporary financial environment ruled by optimization of the principle of capital allocation and strong enough to bear financial jolts. Guidelines have been issued to the policymakers not to limit the assimilation of improved analytics into the supervisory practices where accuracy and efficiency have been considered paramount. The inclusion of perspective in the determinant of TREA within the European banking system could bring up linkages amongst some rather complex interlinkage including regulatory structures of financial stability versus its operating resiliency where an efficient balance in European banking system-derived risk-taking and associated oversight or prudent regulation with regard to capital adequacy matching the exposition to risk coupled and supported by improvements in technology that would be effected. The contributions to the growing debate on risk management thus form an important avenue for improving the situation of global financial stability.

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