POLITECNICO DI TORINO

Master of Science in Engineering and Management

Master Thesis

The Targeted Review of Internal Models: Assessment of the quality of data used for IRB modelling purposes

Supervisor

Prof. Luigi Benfratello

Candidate

Federica Del Gaudio

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A Mamma e Papà,

miei instancabili sostenitori.

A mio fratello e mia sorella,

sempre presenti, da vicino e da lontano.

Grazie.

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INTRODUCTION

Through this work I aim at analysing the quality, and more extensively, the governance of the data used in the context of internal ratings-based approach for the purpose of the estimation of the risk parameters contributing to the credit risk, specifically the probability of default, the loss given default and the exposure at default. The starting point of the presented considerations has been the topics faced during my curricular and extracurricular internship in Accenture S.p.A., the renowned consulting company. During my working experience I had the possibility to follow a project within the "Regulatory and Compliance" area in the context of "Finance and Risk", initiated by an important Italian banking group. Specifically, the Project Manager Officer (PMO) role within the risk management IT department has introduced me to the knowledge of credit risk management from the perspective of IT infrastructure, providing me at the same time with a cross and complete vision of all the aspects related to the project.

Nowadays data are probably the most valuable assets owned by the companies. This also applies to data used by banks in their internal models to calculate credit risk. Indeed, since 2004 with Basel II, banks are allowed to use internal estimates of the risk parameters to compute the credit risk and the related regulatory capital which they are required to hold. If, on one side, this option represents an advantage for banks because it enables them to hold capital proportionate to the effective risk that they bear, on the other side, this opportunity constitutes a danger since an inaccurate estimate of the parameters contributing to the rise of credit risk may lead to an underestimation of the risk itself and the related regulatory capital to hold, driving banks to hold in crisis situations less capital than effectively needed. With the objective of preventing such situation and the potential systemic risks that it would entail, European Central Bank (ECB) started a number of initiatives designated to examine the internal models used by banks to calculate risk; it is in this context that the Targeted Review of Internal Models (TRIM) lies.

The final scope of this thesis is therefore to analyse the actions undertaken by the relevant banking group in response to the initiative launched by the ECB, describing in detail the project started by the bank to improve the quality of risk data. Moreover, in order to evaluate the significance of the variation in data quality following the execution of the project, a quantitative analysis is presented.

The thesis is subdivided in *six* subchapters:

The *first* chapter introduces the main services offered by the financial sector, explaining the reasons why a close supervision of this sector is needed. Then, the wide framework of the prudential regulation is applied to the specific case of banks, describing the main actors involved in this context and the different approaches (micro and macro regulation) that they may adopt. Finally, the Single Supervisory Mechanism (SSM), the ECB body dealing with the prudential supervision of all credit institutions in the participating Member States of European Union, is described.

The *second* chapter starts with an overview of the Basel Committee on Banking Supervision (BCBS), the main body responsible for the prudential regulation of banks, and its objectives. It then focuses

on the three Basel Accords, showing the evolution of the proposed standards over time and highlighting how the weaknesses of each Basel Accord have been overcome by the ones issued later.

The *third* chapter shifts the attention on credit risk and the internal models used by banks for computing it. Their main elements are therefore presented: risk exposures classification; risk components (probability of default, loss given default, exposure at default and maturity); risk functions enabling the transformation of the mentioned risk components in banks' capital requirements; finally, the necessary requirements to be satisfied by banks for obtaining the permission to use internal models.

The *fourth* chapter introduces the Targeted Review of Internal Models (TRIM), a project launched by the ECB to evaluate the compliance of the internal models used by banks with regulatory requirements. Starting from the issues identified by the ECB during this review, the work focuses particularly on the quality of data used in the IRB approach. The data quality topic is thereafter discussed, underlying the problems that may originate for inaccurate data, then presenting another regulation proposed by the BCBS with the objective of improving both quality and management processes of risk data, and finally displaying the elements used by the ECB to evaluate the level of adequacy of data quality within the TRIM context.

The *fifth* chapter describes the TRIM Data Quality Credit Risk, a project started by the bank in question in response to the findings, related to the quality of data used for PD, LGD and EAD models estimation, identified by the ECB during the on-site inspections carried out within the context of the initiative defined before. Following a general overview on the project structure and objectives, an estimate of its cost for the period under consideration, conducted on the basis of the information collected during my internship, is provided. Moreover, the deliverables produced by the working groups involved in the project are represented in detail.

The *sixth* chapter aims at analysing in quantitative terms the actual influence of the project carried out on data quality variation. For this purpose, by using data made available during my internship, two key quality indicators (KQI) have been computed. At first, the evolution over time of these indicators, and consequently of the underlying data, is showed. Subsequently, the results of the Mann-Whitney U test, conducted with the goal of measuring the significance of data quality change before and after the project, are exhibited.

CHAPTER 1 - PRUDENTIAL REGULATION

1.1 Introduction to the financial sector

Across time and space, the primary function of a financial system is to facilitate the distribution and deployment of economic resources in an uncertain environment. More in detail, the financial sector should provide the following four services:

1. Value exchange: a safe and efficient payment system is essential to support the day-to-day business of an economy. An efficient payment system should be:
   - Timely: while not all transactions are urgent, the possibility of giving recipients timely access to funds is useful;
   - Accessible: everyone who needs to make and receive payments should have ready access to the payments system;
   - Easy to integrate with other processes: this includes the reconciliation and recording of information by the parties involved (which should also be timely and accessible);
   - Easy to use: this is not only an issue of convenience but also of minimising errors;
   - Safe and reliable: end users of a payments system need to be confident that the system is secure; that is, that their confidential information is protected. They also need to have confidence that the system will be available when needed;
   - Affordable and transparent: users can make well-informed choices about payment methods according to their cost and convenience;
2. Intermediation: the financial sector sits between savers and borrowers; it takes funds from savers and lends them to those who wish to borrow, be they households, businesses or governments. Intermediation can take on many forms beyond the traditional banking service of taking deposits and making loans, the common thread is that a financial institution stands between the counterparties to a transaction. Depending on the nature of the transaction, a number of supplementary functions may be required to intermediate between savers and borrowers, including:
   - Pooling resources: for example, a bank can combine a number of small deposits to make a large loan;
   - Asset transformation: financial intermediaries provide a link between the financial products that firms want to issue and the ones investors want to buy. This includes issuing securities to savers at short maturities, while making loans to borrowers at long maturities (process known as maturity transformation);
   - Risk assessment and information processing: financial intermediaries have expertise in screening potential borrowers to identify profitable lending opportunities, taking into account the risks that these entail;
   - Monitoring borrowers: financial institutions take steps to limit the misuse of savers' assets. This function is critical to the decision by savers to lend their money in the first place, and hence for facilitating investment in the economy;

- Accurate accounting: together with a legal system that enforces property rights, prudent measurement is vital in enabling depositors, shareholders and investors to be paid what they are entitled to;

3. Risk transfer: a well-functioning financial system facilitates the pricing and allocation of certain risks. The financial sector should allow individuals to tailor their exposure to risk to suit their preferences. Importantly, the role of the financial sector is not to remove risk entirely; rather, it should facilitate the transfer of risks to those best placed to manage them. It cannot remove many of the risks within the economy, which must ultimately be borne by individuals either as holders of real and financial assets, or as taxpayers. Moreover, it is not the goal of the financial sector necessarily to minimise risk. The socially optimal amount of risk is almost certainly not the minimum feasible level, given the importance of risk-taking to innovation and entrepreneurship;
4. Liquidity: the financial sector provides liquidity. If the financial system is working well, individuals, businesses, and governments are able to convert their assets into cash at short notice, without undue loss of value. The provision of liquidity is useful to individuals for meeting unexpected obligations. It is also critical to society at large because access to liquidity allows businesses to deploy their capital in ways that increase the productive capacity of the economy. Without it, households and businesses would be forced to hold larger sums of cash to protect against unforeseen events. The result would be fewer resources for investment and the provision of fewer goods and services to consume.

Each of the four core functions are vital to economic progress and its presence, i.e. financial stability, contributes materially to our economic well-being, while their absence, i.e. financial instability, imposes great costs. First of all, the financial sector is an intermediate sector because its activities are mainly directed at promoting efficiency in other sectors. Moreover, the financial sector is a critical link in the functioning of the economy as every economic interaction has a financial component, such as a payment. The spillovers to the real economy from dysfunction or operational failure in the financial and payments systems can be severe. Furthermore, these spillovers can add to moral hazard, whereby financial institutions take risks under the assumption that the resulting costs would be, at least partly, borne by others. The potential for undue risk-taking is exacerbated by the problem of asymmetric information, where the party ultimately bearing the risk is not fully aware of it.

The financial sector is different from the other economic sectors because the absence of the above practices may cause considerable systemic risks. Systemic risk is the probability that a systemic crisis arises. A systemic crisis has three important characteristics: first an initial shock, second a propagation and amplification mechanism, and third disruption of the financial sector. Because such a disruption of the financial sector is very costly for society, its critical role creates a rationale for government intervention and regulatory measures. Thus, the objective of prudential financial regulations is to ensure that the vital functions of the financial sector are maintained.

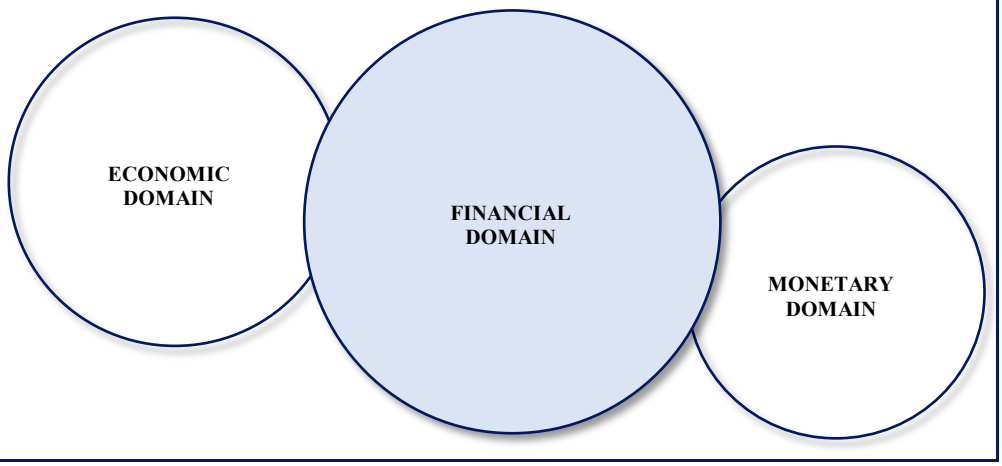
1.1.1. The overall regulatory framework

Regulation may be defined as rulemaking, i.e. the establishment of specific rules of behaviour. Of course, the application of such rules must be supervised and this supervision might be distinguished in micro-monitoring, which refers to observing whether the rules are followed by individual actors or

institutions, and macro-surveillance, which refers to the global observation of the behaviour of financial institutions. As Table 1 shows, prudential regulation and supervision only constitute a specific area in the larger regulatory framework.

Table 1: Policy-matrix of financial regulation and supervisors

OBJECTIVES / SECTORS/ INSTITUTIONS	Competition: Efficiency of market organisation	Conduct of business: Efficiency and integrity of market transactions	Micro prudential Supervision: Soundness of individual institutions	Macro prudential Supervision: Surveillance of stability of the financial system	Monetary policy: Macro-stabilisation
Trading and post-trading Infrastructure					
Investment/Securities Firms					
Insurance Companies and Pension Funds					
Banks: Deposit and Credit Intermediaries					



Source: Dirk Heremans, Dries De Smet (2007), Prudential supervision in an integrating EU financial market.

By looking at the row, it's possible to identify the objectives of the different kinds of regulation. Competition rules aim at the efficiency of market organisation, while conduct of business rules focus on the efficiency and integrity of market transactions. The purpose of micro prudential supervision is the soundness of individual institutions, whereas the intent of macro prudential supervision is the surveillance of stability of the financial system. Finally, monetary policy points to macro-stabilisation. The column lists the major financial sectors and corresponding types of financial intermediaries. Trading and post-trading infrastructure, investment and securities firms, insurance companies and pension funds, banks are to a different degree subject to the different objectives of regulation and supervision.

Prudential regulation and supervision typically refer to the financial domain and may be subject to trade-offs among the different objectives and corresponding regulatory areas.

1.1.2. Causes and effects of prudential regulation and supervision

Financial intermediaries, that emerge due to informational imperfections in financial markets, contribute to the resolution of adverse selection and moral hazard problems by specialising in informational services and monitoring the behaviour of financial market participants. Through their role of appointed supervisors, they help to mitigate agency problems, but in turn they might create other agency problems. Hence, prudential regulation and supervision is responsible for checking the monitors themselves.

As opposed to conduct of business regulation, which deals with the financial transactions as such, prudential regulation concentrates on the regulation and supervision of financial institutions. Indeed, in order to protect the interests of financial market participants, e.g. depositors, insurance policy-holders, the solvency of such financial intermediaries should be guaranteed. Micro-prudential supervision takes on a bottom-up approach, focusing on the safety and soundness of individual financial institutions. This has been the traditional approach of prudential regulators and still remains dominant nowadays.

Financial institutions may also present particular external effects. Since the failure of a financial institution might easily affect the solvency of other financial institutions, it may entail social costs. In this context a distinction can be made between first and second round effects. A first round effect takes place when the institution itself fails due to a financial shock. Then, financial difficulties might spread throughout the institution to branches and subsidiaries, which may also be located abroad. Within financial conglomerates there may also be cross-sectoral effects because banking problems might spread towards insurance, investment and securities firms, or the other way around. A second round effect occurs when the failure is transmitted to other institutions because of explicit financial linkages. In particular, this may be due to domino-effects in the interbank market or in payments systems, or simply to imperfect information of other depositors leading to contagious withdrawals and a bank run. Macro-prudential supervision has a top-down perspective, focusing on systemic stability and avoiding the catastrophic break down of the financial system, interpreted as a complex adaptive system, with many interdependencies among agents who are constantly responding to the activities of other agents.

The high-level objective of prudential regulation is to avoid financial instability; this can be practically achieved by regulation trough the compensation of market failures of various types: the failure of people operating in the system to recognize the externalities associated with their behaviour, excessive short-termism and ignoring of risks, the influence of safety nets and moral hazard. Without regulation, these and other market failures would eventually lead to financial instability and correlated output losses.

In the last decades, the awareness has developed that regulation not only results in benefits for the economy, but it also imposes substantial costs on it.

- Structural regulation limiting the competition of financial markets causes significant welfare costs. Certainly, the costs implicit in the regulation, i.e. lower static and dynamic efficiency of the financial system, must be less than the expected costs of financial instability;
- There is always the danger that regulation produces distortions and further market failures, implying the need for still more regulation. In effect, regulations raise the complexity of the financial system and so the likelihood of instability. For instance, in the prudential field, originally, the emphasis was upon protective instruments, i.e. emergency liquidity assistance by central banks, bail-outs[1] of financial institutions with tax money and followed later by deposit

[1] The difference between a bail-in and a bail-out, both designed to prevent the complete collapse of a failing bank, lies in who bears the financial burden of rescuing the bank. With a bailout, the government injects capital into the banks to

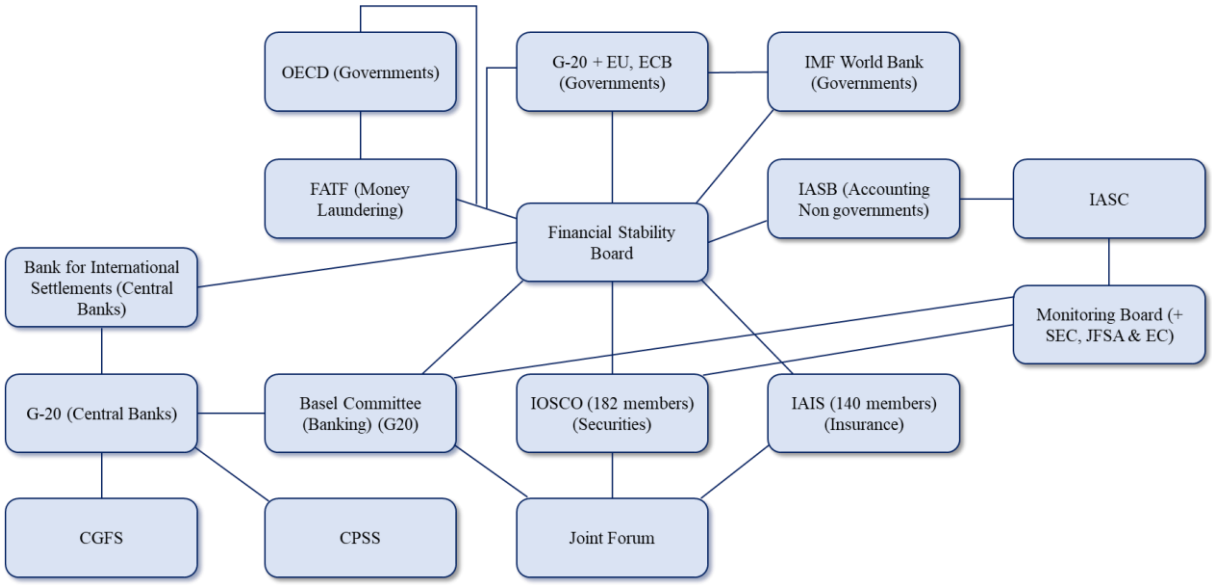
insurance. However, safety nets present moral hazard problems because the financial institutions tend to take more risks. Thus, the need for other prudential policies. Another example is given by the measures to structurally limit competition, which increase the safety of financial institutions, but at a high efficiency cost. Also this case requires the implementation of other prudential instruments to contain risk behaviour of financial institutions;

- Regulations that force many financial agents to behave in the same way can readily worsen systemic issues;
- Regulation in the prudential field imposes a substantial burden on the financial sector. In 2001, according to a World Bank Survey, the figures of regulatory costs amounted to 5.3% of operating profits, 2.8% of value added in banking and 12% of non-interest expenses. Therefore, the regulatory burden should be closely monitored, as more severe regulation does not necessarily lead to an efficient development of the banking system;
- Finally, in complex adaptive systems, all policy actions have unintended and potentially undesirable consequences.

1.2 Prudential regulation of banks

Prudential regulation of banks is only one aspect of global financial regulation; other examples include market surveillance, regulation of trading in financial instruments, insurance regulation, regulation of particular market actors, regulation to prevent/investigate fraud, money laundering and other financial crimes.

Figure 1: Structure of global financial regulations



Source: Black Julia (2013), "Prudential regulation of banks", in International Regulatory Co-operation: Case Studies, Vol.2: Canada-US Co-operation, EU Energy Regulation, Risk Assessment and Banking Supervision.

As the Figure 1 shows, in this field several actors are involved:

enable them to continue to operate. With a bank bail-in, the banks use the money of its unsecured creditors, including depositors and bondholders, to restructure their capital so they can stay afloat.

- Financial Stability Board (FSB): this is the only "supra-committee" because its membership includes the international committees of regulators and other international organisations. FSB was constituted in 2009 out of the Financial Stability Forum and it is a group of G20 financial regulators and finance ministers, the global regulatory committees (BIS and the three committees, IOSCO, IAIS), the International Accounting Standards Board (IASB), the World Bank, the International Monetary Fund (IMF), the European Central Bank (ECB), the European Commission and the Organisation for Economic Co-operation and Development (OECD).

The other actors may be called "meta-organisations" because their membership simply includes national regulators.

- Bank for International Settlements (BIS): it is composed of three subcommittees – Basel Committee on Banking Supervision, Committee on the Global Financial System (CGPS), Committee on Payments and Settlement Systems (CPSS) – whose membership, initially including of the G10 central banks and banking supervisors, was extended to G20 countries in 2009;
    - The Basel Committee on Banking Supervision (BCBS) is the principal body responsible for the formation of global standards relating to banking regulation;
- International Accounting Standards Board (IASB): it is a non-state body of accounting professionals;
- International Organisation of Securities Commissioners (IOSCO) and International Association of Insurance Supervisors (IAIS): they are international committees of national regulators composed of 199 and 190 members respectively.

BCBS, IOSCO and IAIS often operate together through a coordinating committee of the three bodies, the Joint Forum, on issues combining banking, securities and insurance activities.

1.2.1. Micro and macro-prudential measures

Prudential regulatory practices may be intended as initiatives aimed at reducing the expected losses arising from financial instability. This involves a double category of measures: actions to reduce the probability of a default/crisis arising and efforts to lower the losses incurred, in case a default/crisis actually occurs. The former measures are part of the micro-prudential approach, while the latter ones constitute the macro-prudential approach.

- Micro-prudential approach assumes that defaults could happen and, according to its view, the regulatory body should reduce the probability of this occurring. It tries to assure the health of individual financial institutions, supposing that the health of the single institutions is enough to justify the robustness of the whole system. This approach is essentially static in nature. The initiatives implemented by banks to protect themselves against possible credit losses are basically of three different types:
    - Banks price the loan according to its intrinsic riskiness. In a diversified portfolio, occasional losses are normally offset by the extra revenues coming from other risky loans;

- When the perceptions of risk associated to a given loan by the lender changes, he makes loan-loss provisions[2] to cover the expected loss;
- Banks hold capital to face the challenges caused by unexpected losses.

2. Macro-prudential approach strives to reduce the size of the economic costs that might be connected with the happening of a crisis, and is not limited to the attempt to lessen its probability of occurrence, as the micro-prudential one. It concentrates on the stability of the entire financial system and has both a static (cross-sectional) and a dynamic (time-varying) dimension. The former dimension recognizes the strict degree of interdependence among the individual institutions that are part of the financial system, in which the actions undertaken by a financial institution influence the behaviour and the robustness of the others. This implies that "shared shocks" may threaten dramatically the apparently healthy system. This dimension also suggests that special attention should be reserved to banks that are "too big to fail", because of the interdependent relationships in which they are involved. The latter dimension reflects the idea that expected losses are not constant, but change over time due to the inherent "procyclicality" of the financial system. In more detail, the willingness of lenders and borrowers to take on risks tends to increase during the period of cyclical upturn; in turn, this "boom" process, generally driven by leverage, speculation and rapid credit growth, frequently culminates in a costly "bust".

Systemically Important Financial Institutions

Since it has been said that particular attention should be given to "too big to fail" banks, it is interesting to define Systemically Important Financial Institutions (SIFIs). At the moment 29 banks have been classified as SIFIs, implying that they are so large, so interconnected , or so dominant in important spheres of finance that they cannot be allowed to fail, because the systemic implications would be too great. The situation is exacerbated by the uncertainty about the real effects of a possible failure of a SIFI, mostly because of the non-negligible interdependence among large firms. As a result, SIFIs have received attention from the Basel committee and the Financial Stability Board, which decided that a clear distinction should be established among institutions designated as SIFIs and all the others.

One of the actions undertaken by the Basel committee to reduce the expected losses associated with the disorderly failure of a SIFI was the suggestion[3] of higher risk-weighted capital ratios than those imposed on ordinary banks under Basel III, which lower the probability of a disorderly default. However, this measure is not fully convicting. First, the size of the surcharge appears too small to offset the expected costs of a potential SIFI's failure. Second, the initiative is not targeted to either

[2] A loan-loss provision is defined as an expense set aside as an allowance for uncollected loans and loan payments.

[3] Basel Committee on Banking Supervision, "Global Systemically Important Banks: Assessment Methodologies and Higher Loss Absorbency Requirements," November 2011.

the size or the interconnectedness or the concentration, factors responsible for causing systemic damage.[4]

Even though it is far more crucial, resolving a SIFI is surely harder than in the case of a normal bank for two main reasons. First, lots of SIFIs have a very complex legal structure with many legal subsidiaries. Second, SIFIs which operate at international level are subject to different national legislation; moreover, the monitoring of SIFIs requires international co-operation, since they are under the control of both home and host supervisors. In this context, the problem is that in many jurisdictions there are no national procedures enabling co-operation with foreign authorities in the attempt to resolve a SIFI because there are many laws that continue to forbid the sharing of confidential information, necessary for the resolution process. The situation is even more complicated due to other factors. First, individual countries are usually hesitant to cede the sovereignty, although demanded by an ideal solution, leading to a fragmentation in the regulation across countries. Second, individual countries may lose faith in a co-operative solution, thus turning to unilateral action. Third, differences in international practices might impede co-operative solutions. These concerns, of course, influence the question of branches[5] versus subsidiaries[6]. On one hand, banks prefer branches because this choice allows a more efficient pooling of both capital and liquidity; on the other hand, regulators favour separately capitalised subsidiaries, fearing that domestic creditors of cross-border banks might suffer in a crisis.

1.3. Single Supervisory Mechanism

Banking supervision in the euro area is performed by the Single Supervisory Mechanism (SSM), which is a system composed of the European Central Bank (ECB) and the national competent authorities (NCAs) of participating Member States. The SSM builds on the ECB's expertise in the field of macroeconomic and financial stability and on the NCA's knowledge in the supervision of credit institutions within their jurisdictions, considering their economic, organisational and cultural specificities. The SSM is one of the two pillars of the EU banking union, the other one being the Single Resolution Mechanism, which consists of the Single Resolution Board, an EU-level resolution authority, and the Single Resolution Fund and has the purpose of ensuring an orderly resolution of

[4] Admati and Hellwig (*The Banker's New Clothes*) focus on capital requirements (reducing the probability of failure) because they are highly skeptical that measures to reduce the costs associated with a SIFI failure will have any meaningful effect.

[5] A branch is the secondary establishment of the parent company, located in another area. Since it is only a part of the company, it carries out the same activities within the market. The branch is dependent on the parent company and a subordinate relationship between them exists because the branch cannot function without the parent company.

[6] A subsidiary is a legal entity independent from the parent company, i.e. an extension of the same business but in another country. Its control lies with the parent company because it holds a major percentage of the shares and capital of the business. However, the subsidiary runs independently from the parent company, taking its own risks and being subject to the regulations and norms of the country it is in.

failing banks. All euro area countries automatically join the SSM. Participation may also be extended to countries not having the euro as their currency, but who choose to take part of it.

The SSM is responsible for the prudential supervision of all credit institutions in the participating Member States. For this reason, it has to ensure that the EU's policy on the prudential supervision of credit institutions is enforced in an effective and coherent way and that the supervision applied to the credit institutions is of the highest quality. This general intent may be detailed into the three main objectives of the SSM:

1. Ensure the safety and soundness of the European banking system;
2. Increase financial integration and stability;
3. Ensure consistent supervision.

The SSM Regulation confers supervisory tasks on the ECB, necessary to protect the stability of the European financial system, together with the NCAs. The SSM approach is based on a series of principles, which guide the actions of the ECB at the centralised level and of the NCAs at the national level.

- Use of best practices: the aspiration is towards a best practice framework, in terms of objectives, instruments and powers used. Looking for continuous improvements, the methodologies are subject to a frequent review process against both international benchmarks and internal practical experience;
- Integrity and decentralisation: the adopted approach is founded on both centralised and decentralised procedures, the latter benefiting from NCAs' proximity to the supervised credit institutions. All participants cooperate to achieve consistent and high-quality supervisory outcomes;
- Homogeneity within the SSM: credit institutions in the different participating Member States are subject to harmonised supervisory processes in order to avoid unbalanced treatments;
- Consistency with the Single Market: the SSM complies with and contributes to the further development of the Single Rulebook, which intends to provide a single set of harmonised prudential rules that must be respected by institutions throughout the EU. With respect to the supervisory tasks that it can exercise, the ECB supports the convergence process in the Single Market;
- Independence and accountability: the supervisory work is carried out in an independent manner and is subject to democratic accountability at both the European and national level, with the intent of promoting trust in the conduct of this public function in the participating Member States;
- Risk-based approach: the followed approach takes into account the risk, in terms of both the probability of occurrence of a failure of an institution and the impact on the financial stability, such a failure should occur. In this context, those credit institutions judged riskier are reserved closer attention until risks decrease to an acceptable level;
- Proportionality: the intensity of the actions by the SSM varies according to the systemic importance and risk profile of the credit institutions under supervision. This means that its effort is mainly focused on the largest and more complex banking groups;

- Adequate levels of supervisory activity for all credit institutions: minimum, and certainly adequate, levels of supervision are assured for all credit institutions, particularly for the significant ones;
- Effective and timely corrective measures: with the aim of reducing the potential losses for the creditors of an institution, the SSM intervenes as early as possible. Indeed, its approach encourages timely supervisory action and monitoring of a credit institution's response.

1.3.1. The distribution of tasks within the SSM

The SSM supervises around 4,700 credit institutions within the participating Member States, but the responsibility is divided between the ECB and the NCAs on the basis of the significance of the supervised entities.

A credit institution is classified as significant if one or more of the following conditions is met:

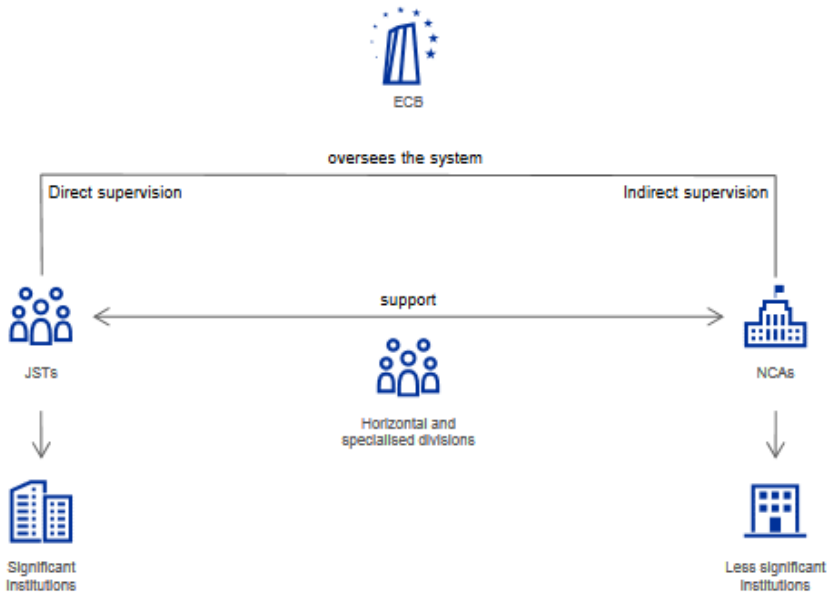
- The total value of its assets exceeds €30 billion or, unless the total value of its assets is below €5 billion, exceeds 20% of national GDP;
- It is one of the three most significant credit institutions established in a Member State;
- It is a recipient of direct assistance from the European Stability Mechanism[7];
- The total value of its assets exceeds €5 billion and the ratio of its cross-border assets/liabilities in more than one other participating Member State to its total assets/liabilities is above 20%.

The SSM conducts a regular assessment of credit institutions for determining the possible fulfilment of those criteria. After these ordinary reviews or following exceptional situations, the status of credit institutions may change, implying a consequent variation in the appointed roles (i.e., if a credit institution becomes significant, supervisory responsibility shifts from the NCAs to the ECB, and the other way around).

The ECB is responsible for the direct supervision of all significant credit institutions, around 120 groups (together account for almost 85% of total banking assets in the euro area) representing approximately 1,200 entities, with the assistance of the NCAs. The NCAs directly supervise less significant credit institutions, around 3,500 entities, under the overall oversight by the ECB.

[7] The European Stability Mechanism (ESM) is an international financial institution, set up by the euro area Member States, with the task of helping euro area countries in severe financial distress. It provides emergency loans but in return, countries must undertake reform programmes.

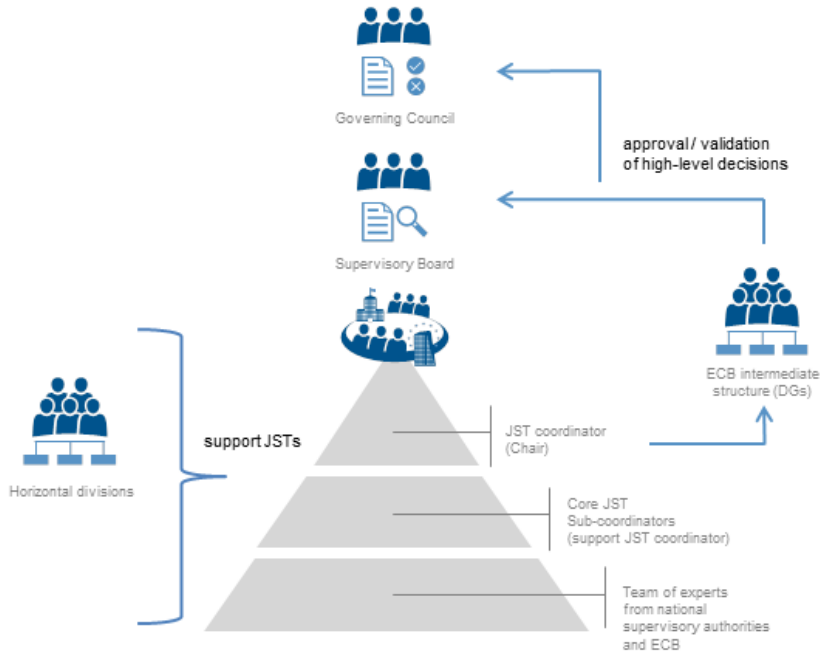
Figure 2: The distribution of tasks within the SSM



Source: ECB Banking Supervision

The day-to-day supervision of significant institutions is performed by Joint Supervisory Teams (JSTs), which include members from both ECB and NCAs of the countries in which the credit institutions, banking subsidiaries or the significant cross-border branches of a given banking group are established. The size, the composition and the organisation of the JSTs vary depending on the nature, complexity, scale, business model and risk profile of the supervised credit institution, thus a specific JST is set up for each institution. Each JST is guided by a coordinator at the ECB, generally from a country different from the place of establishment of the credit institution, who is responsible for the implementation of the supervisory activities. NCAs sub-coordinators of the JST support the coordinator in the day-to-day supervision of significant credit institutions, reflecting in this way the views of the relevant NCAs. They are, in particular, accountable for specific thematic or geographic area of supervision. For certain tasks requiring peculiar technical expertise, additional support may be provided by the horizontal and specialised expertise divisions at the ECB. In the case of JSTs comprising a large number of staff, a core JST, consisting of the JST coordinator at the ECB and (national) sub-coordinators in the NCAs, organises the allocation of tasks among JST members, prepares and revises the supervisory activities and monitors its implementation. The core JST brings the views of the JST members together. JST coordinators are appointed for a period of three to five years, depending on the risk profile and complexity of the institution. JST coordinators and members are expected to rotate on a regular basis. Ten horizontal and specialised divisions of ECB support JSTs and NCAs in the conduct of supervision of both significant and less significant credit institutions.

Figure 3: Functioning of the Joint Supervisory Teams



Source: ECB Banking Supervision

The ECB is also involved in the supervision of cross-border institutions and groups, playing a specific role within the College of Supervisors. These ones have the purpose of ensuring the coordination among the national supervisory authorities responsible for the supervision of different components in cross-border banking group. Within supervisory colleges, the ECB may be:

- Home supervisor for colleges including supervisors from non-participating Member States (European colleges) or from countries outside the EU (international colleges);
- Host supervisor for colleges in which the home supervisor is from a non-participating Member State (or a country outside EU).

The Supervisory Board, composed of the Chair and Vice-Chair, four representatives of the ECB and one representative of the NCAs in each participating Member State, plans and carries out the SSM's supervisory activities and proposes draft decisions to be adopted by the ECB's Governing Council[8].

[8] The Governing Council is the main decision-making body of the ECB and consists of the six members of the Executive Board plus the governors of the central banks of the 19 euro area countries.

CHAPTER 2 - THE BASEL FRAMEWORK

2.1. The Basel Committee on Banking Supervision

2.1.1. The birth of the Basel Committee on Banking Supervision

The Basel Committee on Banking Supervision (BCBS) has its origins in the disorder within the financial market due to the breakdown of the Bretton Woods system of managed international exchange rates in 1973. After the collapse of Bretton Woods, several banks incurred large foreign currency losses. This was the case for the Bankhaus Herstatt, which saw its banking license being withdrawn because the bank's foreign exchange exposures amounted to three times its capital. The banks outside Germany having trades with the Bankhaus Herstatt took heavy losses, and this obviously added an international dimension to the already confused situation. Another dramatic episode was the failure of the Franklin National Bank of New York after having incurred large foreign exchange losses.

In response to these disruptions in the international financial markets, the central bank governors of the G10 countries[9] established a Committee on Banking Regulations and Supervisory Practices at the end of 1974, later renamed the Basel Committee on Banking Supervision.

2.1.2. Purpose and organisation

The BCBS is the primary global standard setter for the prudential regulation of banks and provides a forum for regular cooperation between its member countries on banking supervisory matters. Its mandate is to enhance financial stability by strengthening the regulation, supervision and practices of banks worldwide. It has a specific focus on large, internationally active banks.

The BCBS tries to reach its purpose through the following activities:

- Exchanging information on developments in the banking sector and financial markets, to help identify current or emerging risks for the global financial system;
- Sharing supervisory issues, approaches and techniques to promote common understanding and to improve cross-border cooperation;
- Establishing and promoting global standards for the regulation and supervision of banks as well as guidelines and sound practices;
- Addressing regulatory and supervisory gaps that pose risks to financial stability;
- Monitoring the implementation of BCBS standards in member countries and beyond with the purpose of ensuring their timely, consistent and effective implementation and contributing to a "level playing field[10]" among internationally active banks;

[9] G10 countries: Belgium, Canada, France, Italy, Japan, Netherlands, UK, USA, Germany and Sweden.

[10] Level playing field is a concept about fairness, not that each player has an equal chance to succeed, but that they all play by the same set of rules.

- Consulting with central banks and bank supervisory authorities which are not members of the BCBS to benefit from their input into the BCBS policy formulation process and to promote the implementation of BCBS standards, guidelines and sound practices beyond BCBS member countries;
- Coordinating and cooperating with other financial sector standard setters and international bodies, particularly those involved in promoting financial stability.

Since its inception, the Basel Committee has expanded its membership from the G10 to 45 institutions from 28 jurisdictions[11]. Membership in the BCBS is restricted to organisations with direct banking supervisory authority and central banks. After appropriate consultations, other organisations might be invited to become BCBS observers or members, in the latter case after having checked the importance of their national banking sectors to international financial stability. BCBS membership and observer status is reviewed periodically. The Committee also reports to an oversight body, the Group of Central Bank Governors and Heads of Supervision (GHOS), which includes central bank governors and (non-central bank) heads of supervision from member countries.

2.1.3. Setting standards and monitoring their implementation

When the BCBS develops its standards, it typically starts a public consultation, seeking input from all relevant stakeholders on policy proposals. The consultation is not limited to members, but also non-member authorities through the Basel Consultative Group. All decisions are taken by consensus among BCBS members. The BCBS sets standards for the prudential regulation and supervision of banks, but it has no formal authority and the rules it proposes are per se not legally binding. The BCBS expects full implementation of its standards by BCBS members and their internationally active members, relying on the commitment of the members themselves. That commitment, however, highlights the problem that BCBS members are not legislators; therefore, in order to allow the smooth implementation of the proposed standards, BCBS members should cooperate with the legislators as early as possible and should provide them with all the needed information about the agreed standards and the underlying reasoning. BCBS standards only constitute minimum requirements, thus BCBS members have the option to go beyond them, imposing stricter decisions. The Committee expects standards to be incorporated into local legal frameworks through the rule-making process of each specific jurisdiction within the pre-defined timeframe established by the Committee. In case literal transposition of standards into local legal frameworks is not possible, members should look for the greatest possible equivalence of standards and their outcome.

Guidelines complement BCBS standards by providing additional guidance for the purpose of their implementation. This generally occurs in the critical area of internationally active banks.

Sound practices describe actual observed practices, with the goal of promoting common understanding and developing better supervisory or banking practices. Indeed, BCBS members

[11] Current Members of BCBS: G10 countries, Argentina, Australia, Brazil, China, EU, Hong Kong SAR, India, Indonesia, Korea, Luxembourg, Mexico, Russia, Saudi Arabia, Singapore, South Africa, Spain, Switzerland, Turkey.

should compare these practices with those applied by themselves and their supervised institutions to identify potential areas for improvement.

Beyond proposing standards, the Committee monitors the local enforcement of these standards to assure their timely, consistent and effective implementation, and to contribute to a "level playing field" among internationally active banks. In order to facilitate this process, the Committee adopted a Regulatory Consistency Assessment Program (RCAP), which composes of two steps:

1. Monitoring adoption of the Basel standards;
2. Consistency assessments on a jurisdictional and a thematic basis, evaluating the consistency and the completeness of the domestic regulations, also judging the significance of any deviations.

The RCAP's grading system uses four categories; the regulatory framework can be judged to be compliant, largely compliant, materially non-compliant, or non-compliant.

2.2. Evolution of Basel Accords

The Basel Accords refer to the banking supervision Accords (Basel I, Basel II, and Basel III) issued by the Basel Committee on Banking Supervision (BCBS). They are called the Basel Accords because the BCBS maintains its secretariat at the Bank for International Settlements in Basel, Switzerland and the Committee normally meets there. The Basel Accords is a set of recommendations on banking and financial regulations, specifically, concerning capital risk, market risk, and operational risk. The Accords ensure that financial institutions have enough capital on account to absorb unexpected losses.

2.2.1. Basel I

The Basel Accord of 1988, commonly referred to as Basel I, was proposed by the BCBS, at that time still composed of the governors of the central banks of the G10 Countries, in response to the significant distress affecting the banking sector during the 1980s due to the deterioration of asset quality of banks. The proposed standards were almost entirely addressed to credit risk, the main risk incurred by banks. Credit risk is defined as the risk that the counterparty will fail to perform or meet the obligation on the agreed terms. Particularly, Basel I identified three types of credit risk: on-balance sheet risks; off-balance sheet risks comprising of derivatives, foreign exchange, commodities; and non-trading off-balance sheet risks comprising of forward purchase of assets or transaction related debt assets.

The document consisted of two main sections, covering:

- The definition of the capital, which Basel I decomposed in:

- Tier 1 (core) Capital comprising Paid-up capital[12]; Statutory reserves[13]; Disclosed free reserves[14]; and Capital reserves[15];

  Equity investments in subsidiaries, intangible assets, losses in the current period and those brought forward from previous periods have to be deducted from Tier-I Capital.

- Tier 2 (additional or supporting) Capital including Undisclosed reserves[16] and Cumulative perpetual preference shares[17]; Revaluation reserves[18]; and General provisions[19] and Loss reserves[20].

- The structure of risk weights of bank assets, which were classified into four categories depending on their credit risk, respectively: 0% - zero risk, 20% - low risk, 50% - medium risk and 100% high risk.

  Banks also had to establish the assets falling into each category, as reported in Table 2.

The calculation of risk weighted assets (RWA) as documented in the Basel I framework is as follows:

$$RWA = 0 \times (bucket\ 1) + 0.2 \times (bucket\ 2) + 0.5 \times (bucket\ 3) + 1 \times (bucket\ 4)$$

[12] Paid-up capital is defined as the actual initial capital of the bank.

[13] Statutory reserves are reserve requirements of a bank as prescribed by respective central banks of the country, and can be in the form of government security investment, gold, cash or any other secured securities.

[14]Disclosed free reserves are the reserves a bank holds in excess of required reserves, minus reserves borrowed from the central bank, which appear on publicly available documents.

[15] Capital reserves represent surplus arising out of sale proceeds of assets of the bank.

[16] Undisclosed reserves include the unpublished or hidden reserves of a financial institution that may not appear on publicly available documents, but are nonetheless real assets, accepted as such by most banking institutions.

[17] Cumulative perpetual preference shares are shares which have no maturity and come with loss absorption clause.

[18] Revaluation reserves get generated in the books of the bank when the current and probable future value of the assets is higher than their historic cost.

[19]General provisions are balance sheet items representing funds set aside by a company as assets to pay for anticipated future losses.

[20]A loss reserve is an estimate of an insurer's liability from future claims on insurance policies it underwrites.

Table 2: Asset Classes and Weights

Weight	Asset type
0 %	Cash held
	Claims on OECD central governments
	Claims on central governments in national currency
20 %	Cash to be received
	Claims on OECD banks and regulated securities firms
	Claims on non-OECD banks below 1 year
	Claims on multilateral development banks
	Claims on foreign OECD public-sector entities
50%	Residential mortgage loans
100%	Claims on the private sector (corporate debt, equity, etc.)
	Claims on non-OECD banks above 1 year
	Real estate
	Plant and Equipment

Source: Basel Committee on Banking Supervision (2005), An Explanatory Note on the Basel II Internal Rating Based Risk Weight Functions, BIS, Bank for International Settlements.

After having identified the capital and having assigned risk weights to the assets, banks had to compute the Capital to Risk Weighted Assets Ratio (CRAR), also referred to as Capital Adequacy Ratio (CAR), defined as the minimum level that banks had to maintain between capital and assets weighted by risk level. The minimum stipulated value for this indicator was 8% if it was computed as the ratio between the total capital (Tier I + Tier II) and the RWA, and 4% if it was calculated as the ratio between the Tier-I capital and the RWA.

$$Total\ CRAR = [Eligible\ total\ capital\ funds/Credit\ RWA] \geq 8\%$$

$$Tier\ 1\ CRAR = [Eligible\ Tier\ 1\ capital\ funds/Credit\ RWA] \geq 4\%$$

Basel Accords of 1988 was originally meant for banks in G10 countries, but its merits were so largely recognized that during the 1990s it became an accepted world standard, with more than 100 countries applying the Basel framework to their banking system. Though the initial focus was on the management of credit risk, after few years it was felt the need to incorporate market risk too. Market risk is defined as the risk to a bank's financial condition that could result from adverse movements in market prices (i.e., equity prices, foreign exchange rates, interest rates and commodity prices). Therefore, through an amendment of Basel I in 1996, market risk was introduced in the framework along with two methods for calculating it, namely the Standardised Approach and the Internal Models Approach, both described in the next section.

The merits which can be recognized to Basel I include the following:

- Substantial increase in capital adequacy ratios of internationally active banks;
- Relatively simple structure;

- Worldwide adoption;
- Increased competitive equality among internationally active banks;
- Greater discipline in managing capital;
- A benchmark for assessment by market participants.

When in 1988 Basel I was introduced, financial transactions were rather simple. But during the following years financial environment evolved as new financial institutions came into existence and innovative products and services were offered, thus the nature of financial risks started changing. All these transformations showed some shortcomings of Basel I:

- The lack of risk sensitivity (i.e. a corporate loan to a small company with high leverage and a loan to a AAA-rated large corporate company are both risk-weighted at 100%, so they consume the same regulatory capital);
- A limited recognition of collateral with respect to those effectively used by banks to mitigate their risks;
- An incomplete coverage of risk sources because Basel I only focuses on credit risk and later, with the Market Risk Amendment, on market risk, but it still lacks other risk types;
- A "one-size-fits-all" approach as the requirements are not differentiated depending on the risk level, sophistication and activity type of the bank;
- An arbitrary measure because the minimum value of 8% of the CRAR is arbitrary and not based on explicit solvency targets;
- No recognition of diversification through granting loans to various sectors and regions, indeed the credit risk requirements are only additive;
- No recognition of term structure of credit risk because the capital charges are all set at the same level, independently from the maturity of a credit exposure;
- Inadequate assessment of risks and effects of the use of new financial instruments and insufficient risk mitigation techniques;
- Simplified calculation of potential future counterparty risk, which ignores the different level of risks associated with different currencies and macro-economic risk by assuming a common market to all actors.

2.2.2. Basel II

Critics claimed that Capital Adequacy Ratios were not enough to evaluate the true risk potential of a bank. Moreover, Basel I, by focusing only on key financial risk metrics, completely ignored the need for a robust risk management process. In order to address these issues, in 2004 the BCBS came up with Basel II, a series of rules to address the post-1988 financial climate, which transformed the 1988 Basel Accord's primitive capital adequacy rules into a more general risk management regime. It proposed more elastic, institution-specific requirements, abandoning the "one-size-fits-all" approach.

Basel II is based on three pillars:

1. Minimum Capital Requirements;

2. Supervisory Review Process;
3. Market Discipline.

Pillar 1: Minimum Capital Requirements

The calculation of Minimum Regulatory Capital has its origins in the 1988 Basel Accord, extending however the initial framework. Indeed, in addition to credit and market risk, Basel II also takes into account operational risk. Operational risk is the risk of direct or indirect loss resulting from inadequate or failed internal control processes, people, systems or from external events. The formulae for the computation of CRAR are similar to those include in Basel I. The minimum value recommended for Total CRAR is 8%, while the minimum value suggested for Tier I CRAR is 4%.

$$Total\ CRAR = Eligible\ total\ capital\ funds/[Credit\ RWA + Market\ RWA + Operational\ RWA] \geq 8\%$$

$$Tier\ 1\ CRAR = Eligible\ Tier\ 1\ capital\ funds/[Credit\ RWA + Market\ RWA + Operational\ RWA] \geq 4\%$$

The first factor to be considered is the Eligible Capital, still divided into Tier I and Tier II Capital, with the former more stable and risk absorbing than the latter:

1. Tier I (core) Capital comprising Paid up capital, Statutory reserves, Disclosed free reserves, Capital Reserve, Eligible innovative perpetual debt instruments (IPDI – up to 15% of Tier I capital), Perpetual non-cumulative preference shares (PNPS – IPDI and PNPS together cannot overcome 40% of Tier I capital);
2. Tier II (additional or supporting) Capital including Revaluation reserve (at a discount of 55%), General provision and Loss reserves, Hybrid debt capital instruments[21] (e.g., perpetual cumulative preference shares, redeemable non-cumulative preference share, redeemable cumulative preference share), Subordinate debt[22] (fully paid up, unsecured, subordinated to other creditors, free of restrictive clauses), Remaining IPDI e PNPS from Tier I capital.

The second element that should be taken into account is the computation of the Risk Weighted Assets. Thanks to the Basel II framework, banks having better asset quality are subject to reduced capital requirements, since lower risk weights can be assigned to good assets.

For assessing the credit risk, the 2004 Basel Accord proposes three implementation options:

1. Standardised Approach: this method has fixed risk weights corresponding to various risk category based on ratings assigned by approved external credit rating agencies. The risk weights range between 0% and 150% based on the risk category. Unrated loans have 100% risk weights. This approach has higher risk sensitivity than the one proposed by Basel I because a wider list of

[21] Hybrid debt capital instruments are securities which combines two or more debt and capital instruments e.g. a convertible bond.

[22] Subordinate debt is a debt instrument that ranks below other debts with regard to its claim on assets and earnings.

collateral, guarantees and credit derivatives is included. Furthermore, the risk weights for residential mortgage exposure are lower than before.

2. Foundation Internal Rating Based Approach (IRB Approach): with this method, credit risk is measured on the basis of internal ratings given by the bank, and not by external credit rating agencies. These ratings depend on the risk characteristics of both the borrower and the specific transaction. The metrics used to compute the loss are the following:
   - Probability of default (PD) measures the likelihood that the borrower will default over a given time horizon;
   - Loss given default (LGD) measures the proportion of the exposure that will be lost if default occurs;
   - Exposure at default (EAD) represents the estimated amount outstanding in a loan commitment if default occurs;
   - Maturity (M) measures the remaining economic maturity of the exposure.

   PD is computed by the banks; the other measures are provided by the BCBS.

3. Advanced Internal Rating Based Approach (Advanced IRB Approach): the only difference in this advanced version is that LGD, EAD and M too are estimated by the bank based on historical data, with the approval of the supervisory institution.

A comparison among the previous described three methods is shown in Table 3.

Table 3: Credit risk assessment approaches

Data Input / Approach	Standardised Approach	Foundation IRB	Advanced IRB
Probability of Default	Predicted by External Credit Rating Agency	Provided by bank based on own Estimates	Provided by bank based on own estimates
Loss Given Default		Supervisory values set by Basel Committee	Provided by bank based on own estimates
Exposure at Default		Supervisory values set by Basel Committee	Provided by bank based on own estimates
Maturity		Supervisory values set by the Committee or at National discretion provided by bank based on own estimates	Provided by bank based on own estimates
Data Requirement		Historical data of 5 years	Historical data of 7 years

Source: Debajyoti Ghosh Roy, Bindya Kohli, Swati (2013), "Basel I to Basel II to Basel III: A risk management journey of Indian banks", in AIMA Journal of Management and Research.

Basel II introduces three methods aimed at the calculation of operational risk:

1. Basic Indicator Approach (BIA): according to this method, to cover operational risk banks must hold capital equal to the average over the previous three years of a fixed percentage of positive annual gross income. The guidelines specify that the annual gross income must be positive,

implying that figures for any year of negative or zero annual gross income should be excluded from both the numerator and denominator when computing the average.

2. Standardised Approach (SA): this method requires the division of bank's activities into eight business lines[23]. The capital charge for each business line is computed by multiplying the gross income by a factor (called beta), which is assigned to that business line. The total capital charge is calculated as the average over the previous three years of the summation of the regulatory capital charges across each of the business lines in each year.
3. Advanced Measurement Approach (AMA): with this approach banks are allowed to develop their own empirical model to quantify required capital for operational risk, under prior approval of supervisory authorities. Even if the use of a specific modelling technique is not mandatory, one of the most common methods is the loss distribution approach (LDA), which requires the division of operational losses into homogeneous segments, called units of measure, and the construction for each unit of measure of a loss distribution representing bank's expectation of total losses in a one-year horizon. Then, the bank develops a frequency distribution describing the number of loss events in a given year, and a severity distribution representing the loss amount of a single loss event. The convolution of these two distributions generates the annual loss distribution.

In order to compute market risk, Basel II retains the same approaches defined in the amendment of Basel I:

1. Standardised Approach (SA): under this approach, the capital charge is the sum of specific risk and general market risk. While specific risk of tradable instruments is the risk associated with the particular security, general market risk is the risk associated with the market scenario. In the field of general market risk, financial instruments may be grouped based on their maturity or their duration. Maturity stands for the last payment date of a financial instrument; on this maturity date, both the outstanding principal and any remaining associated interest are owed and expected to be rendered for final payment. Duration is a first-order measure of a financial instrument's price sensitivity to changes in yields, where the yield is the market interest rate. Macauley duration is defined as follows:

$$D_{mac} = \frac{\sum_{t=1}^{T} \frac{t \times C_t}{(1+y_1)^t}}{\sum_{k=1}^{T} \frac{C_k}{(1+y_1)^k}}$$

where:

- y_1 = Annually compounded yield

- C_t = Generic cash flow at the end of year t

To each bucket an assumed yield change is associated, based on which sensitivity can be computed. According to the approach based on maturity, Basel II considers the empirical based

[23] Business lines of bank's activities: Corporate finance, Trading and sales, Retail banking, Commercial banking, Payments and settlements, Retail brokerage, Asset management

assumed yield change, which is the approximate change in yield in two-year bucket. Depending on this assumed yield change, maturity and market value of the instrument, capital charge for general market risk is assessed. The approach based on duration allows to link a change in yield to the percentage change in the price of the instrument:

$$\frac{\delta P}{P} \approx -D_{mod} \times \delta y_1$$

where modified duration is defined as $D_{mod} = \frac{1}{1+y_1} \times D_{mac}$.

The determined change in market price works as a base for computing capital charge. Generally, duration-based bucketing is recommended.

2. Internal Models Approach (IMA): this method allows banks to develop their own internal models to calculate market risk on a case-by-case basis. Differently from the standardised approach, the focus of most internal models is merely a bank's general market risk exposure, typically leaving specific risk to be measured largely through separate credit risk measurement systems. Banks using internal models should be subject to capital requirements for the specific risk not captured by their models; this implies that a separate capital requirement for specific risk will apply to each bank using an internal model to the extent that the model does not capture specific risk. Concepts like VaR[24] and stressed VaR form an integral part of capital charge computation. Based on the VaR calculation, the riskiness of financial instruments is assessed and RWA is evaluated, allowing consequently the prediction of capital requirements. VaR can be computed based on historical data or random variables.

Pillar 2: Supervisory Review Process

The second Pillar is the regulatory response to the first Pillar because regulators are given the power to oversee the internal risk evaluation regimes proposed in Pillar I. Moreover, through Basel II regulators are provided much improved tools to supervise and check bank's risk management system and capital assessment policy than those available to them under Basel I. It also provides a framework for dealing with all the other risks that a bank may face, such as reputation risk, liquidity risk and legal risk, which together are defined residual risk.

The Committee has identified four key principles of supervisory review:

1. Principle 1: banks should implement a process to assess their capital adequacy in relation to their risk profile and a strategy to maintain their capital levels;
2. Principle 2: supervisors should review and evaluate banks' internal capital adequacy assessments and strategies and their ability to monitor and ensure their compliance with regulatory capital ratios. If supervisors are not satisfied with the outcome of this process, they should take appropriate actions;
3. Principle 3: banks are expected to operate above the minimum regulatory capital ratios, therefore supervisors should have the option for requiring banks to hold capital in excess of the minimum;

[24] Value at Risk (VaR) method is a statistical approach for the evaluation of market risks. The aim of the VaR model is to calculate consistently the loss, with a specified probability, over a specified holding period of time, which a bank might experience on its portfolio from an adverse market movement.

4. Principle 4: supervisors should intervene at an early stage in order to prevent capital from falling below the minimum levels required for a bank and should require quick remedial actions if capital is not maintained or restored.

Pillar 3: Market Discipline

Market discipline complements regulation because the sharing of information simplifies the assessment of the bank by market participants, including investors, analysts, customers, other banks and rating agencies, which leads to good corporate governance. Market discipline is enabled to operate since this Pillar requires institutions to disclose details on the scope of application, capital, risk exposures, risk assessment processes, and the capital adequacy of the institution. The Committee introduces disclosure recommendations as well as disclosure requirements. These latter are connected with the use of a particular instrument or methodology and represent pre-conditions for the use of such instrument or methodology for regulatory capital purposes. Regular publication of information is required for the institutions (every six months for the national banks and every three months for the internationally active banks).

Over time, drastic changes affected the global financial environment, leading to the Financial Crisis of 2008-09, which highlighted the numerous shortcomings of Basel II:

- False sense of security: one of the most critic problem was the illusion that compliance with Basel II automatically meant the banks would be adequate to face a crisis. Since the authorities and market actors looked at Basel II as an almost complete system of bank regulation, they overlooked systemic risk due to the presence of Basel II-compliant national regulation. The confidence in Basel II originated from two different elements. The first aspect was the trust that other actors were following Basel II and thus were, at least in a small part, robust. The second factor was the trust that Basel II had been designed well enough that when financial institutions complied, a systemic breakdown was considered virtually impossible;
- Reliance on rating agencies: during the period before the crisis, rating agencies were not able to recognise the risk of certain innovative financial assets, indeed, the accuracy of several pre-crisis ratings of complex financial products appears doubtful. Furthermore, ratings did not reflect the increase of correlated defaults during period of financial stress. Finally, ratings did not seem to carry any objective content, no longer expressing the probability of default and expected recovery rates upon;
- Cyclicality: procyclicality is defined as the negative spiral effect resulting from the correlation between asset value declines and Basel II's rigid capital demands. The process is the following – in good times, when asset value increases, capital is generated in order to support asset growth; in difficult times, when asset value declines, banks are constrained to raise additional capital to support the same asset portfolio they previously held. Generally, during a downturn the cost of capital may rise. In order to return compliant banks might dispose of the assets, but, in turn, the wide offer of assets into the market lead to the further reduction in asset values. Therefore, Basel II creates a tendency to generate increasingly decline in asset values.

2.2.3. Basel III

A common shortcoming of the first two Basel Accords consisted in the fact that they approached the solvency of each institution independently. This conceptual mistake was soon pointed out by the 2008 financial crisis, which showed the systemic risk that the failure of one large institution could cause the failure of one or more of its counterparties, triggering in this way a chain reaction. Basel III, issued by the BCBS in December 2010, were designed to address the catastrophic loss which had contracted institutional lending and locked down capital holdings due to the Lehman Brothers collapse. The key aim of these reforms was to strengthen the banking sector's safety and stability trough the improvement of the quality and quantity of capital components which banks must hold in order to absorb losses, leverage ratio, liquidity standards and increased disclosures.

A first feature of the 2010 Basel Accord is represented by enhanced capital requirements. Banks were required to hold more reserve, with Common Equity[25] requirements raised from 2% to 4.5%. Also Tier 1 Capital requirements, where Tier 1 Capital depicts the mandatory reserve, were increased from 4% to 6%. The composition of capital is the following:

a. Tier 1 Capital (going-concern capital)
   - Common Equity Tier 1 (CET1)
   - Additional Tier 1 (AT1)

b. Tier 2 Capital (gone-concern capital)

$$[CET\ 1/Total\ RWA] \geq 4\%\ (minimum\ value)$$

$$Tier\ 1\ CRAR = [Eligible\ Tier\ 1\ capital\ funds/Total\ RWA] = [(CET\ 1 + AT\ 1/Total\ RWA] \geq 6\%$$

A mandatory Capital Conservation Buffer, an additional reserve of 2.5%, was introduced in order to withstand future periods of stress, bringing the total Common Equity Tier 1 Capital reserves required to 7%. This buffer was included to meet one of the key objectives expressed by the BCBS, that is to conserve enough capital to build buffers, at the level of both individual banks and the entire banking sector, which can then be used in times of stress.

$$[CET\ 1/Total\ RWA] \geq 7\%\ (total\ value)$$

A discretionary Countercyclical Buffer, through which bank regulators can increase their capital requirements in periods in which credit grows faster than GDP, was established too. The reason behind its creation lied in the responsibility for local regulators of regulating credit volume in their national economies, in addition to controlling banks' compliance with the Basel requirements. This buffer, which varies between 0% and 2.5%, may preserve national economies from excess credit growth.

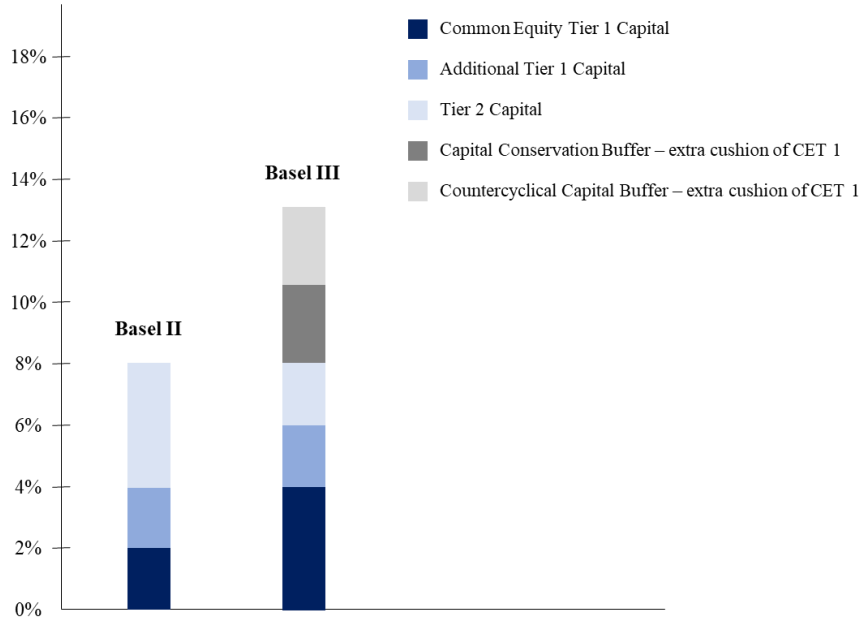
[25] Common Equity is composed of the common shares (or comparable instruments) and retained earnings.

Capital requirements were supplemented by a non-risk-based Leverage Ratio, measured as the ratio of Tier 1 Capital to Total Assets, which substitutes the risk-based one comprised in the Basel II framework. According to Basel III, Tier 1 Capital has to be at least 3% of Total Consolidated Assets[26] even when there is no risk weighting, and this requirement may limit banks' scope of action.

$$[Eligible\ Tier\ 1\ capital\ funds/Total\ Exposure] \geq 3\%$$

Figure 4 shows the difference in the capital requirements imposed by Basel III with respect to Basel II.

Figure 4: Increased capital requirements in Basel III



Source: Accenture

In order to provide a better liquidity risk management, two new instruments were instituted. The short-term Liquidity Coverage Ratio (LCR) aims at ensuring that a bank maintains an adequate level of unencumbered, high-quality assets which can be converted into cash to meet its liquidity needs for a 30-day time horizon under a critical liquidity stress scenario specified by supervisors. The long-term Net Funding Stability Ratio (NFSR) has the purpose of guaranteeing that investment banking inventories, off-balance sheet exposures, securitisation pipelines and other assets and activities are funded with at least a minimum amount of stable liabilities in relation to their liquidity risk profiles. This latter is defined as the ratio, for a bank, of its "available amount of stable funding" divided by its "required amount of stable funding". In accordance with the standard, both ratios cannot be lower than 100%.

$$LCR = [High - quality\ liquid\ assets/Total\ net\ liquidity\ outflows\ over\ 30\ days] \geq 100\%$$

[26] Total consolidated assets are given by the sum of the exposures of all assets and non-balance sheet items.

$$NFSR = [Available\ amount\ of\ stable\ funding / Required\ amount\ of\ stable\ funding] \geq 100\%$$

The potential impact of Basel III on the banking system is significant. Indeed, Basel III improved the shortcomings characterising Basel II in four areas:

- Higher capital requirement: Basel III rules require higher and better-quality capital. In Basel II the minimum total capital required is given by 8% of RWA. In Basel III this one remains unchanged, but a capital conservation buffer of 2.5% of RWA over and above the minimum capital requirement is introduced, raising the total capital requirement to 10.5% against 8% under Basel II. Thanks to this buffer banks should be able to absorb losses without breaching the minimum capital requirement and carry on business even in a downturn without deleveraging. This buffer is not part of the regulatory minimum; however, its level will determine the dividend distributed to shareholders and the bonus paid to staff;
- Liquidity standards: in order to mitigate liquidity risk, Basel III norms address both short-term liquidity stress and long-term structural liquidity mismatches in banks' balance sheets. Short-term liquidity stress is covered through the keeping by banks of sufficient high-quality unencumbered liquid assets to resist any stressed funding scenario over a 30-day horizon, as measured by the LCR. For remedying to liquidity mismatches in the longer-term banks are required to maintain a NSFR, which commands a minimum amount of stable sources of funding relative to the liquidity profile of the assets and to the liquidity needs that may arise from off-balance sheets commitments over a one-year horizon. In simpler terms, the objective of the NSFR is to encourage banks towards stable sources of funding;
- Provisioning norms: the BCBS supported the adoption of an "expected loss" based measure of provisioning, which is able to capture losses more transparently and is also less procyclical than the previous "incurred loss" approach. The expected loss approach for provisioning makes financial reporting more useful for all stakeholders, including regulators and supervisors;
- Disclosure requirement: the disclosures made by banks are fundamental for market participants, allowing them to make informed decisions. One of the lessons learned with the crisis is that the disclosures made by banks on their risky exposures and on regulatory capital were neither appropriate nor sufficiently transparent to afford any comparative analysis. To overcome this shortfall, Basel III required banks to disclose all relevant details, including any regulatory adjustments, as regards the composition of the regulatory capital of the bank.

CHAPTER 3 - INTERNAL RATINGS BASED APPROACH OVERVIEW

After having described in a general way all the elements introduced by Basel accords, the focus now shifts to the internal models used by banks to compute the risks. Most of the largest banks decided to adopt the internal methods, instead of the standardised ones, because the latter did not appropriately reflect risk and resulted in much higher capital requirements, while the former led to capital requirements more consistent with the level of risk taken, allowing a more efficient use of resources. In fact, while standardised approach relies on conservatism, internal approach leans on accuracy of risk estimation. Credit risk can be considered as one of the major risks faced by banks because it is associated with every active trade, therefore the following discussion will be only limited to it and to the IRB approach.

3.1. Credit risk definition

Credit risk can be defined as the risk of an unexpected variation in the credit standing of a counterparty leading to a consequent unexpected variation in the current value of his credit exposure. On the basis of such indication, credit risk can be classified in five different categories:

1. Credit default risk: this occurs when the loss arises from the complete default of the counterparty. A counterparty is considered to be in default when the creditor bank judges impossible for the debtor to cope with his obligations or when 90 days (past due) have passed since the maturity of the position;
2. Migration risk: this occurs when the variation in the credit standing of a counterparty generates a loss in the value of the position or increases the probability of a future default. The deterioration in the creditworthiness of a counterparty may happen after a downgrading, i.e. the downward revision of a counterparty's rating; the effect of such phenomenon is identical both considering issuers of financial instruments listed on the financial markets, to which a rating is assigned by qualified credit rating agencies (Fitch, Moody's and Standard & Poor's), and when the downgrading is related to the bank's internal credit scoring models, on the basis of which the probability of default (PD) and the loss given default (LGD) are estimated. In both cases, the bank has to revaluate the current value of the exposure towards the debtor by adjusting the rate used to discount the future cashflows arising from the exposure, which incorporates the risk premium and so reflects the counterparty's probability of default. Specifically, the occurring of a downgrading entails an increase in both the probability of default and the risk premium, with a consequent reduction in the current value of the bank's credit exposure;
3. Recovery risk: this occurs when the recovery rate (RR) of a given credit operation proves to be lower than expected due, for instance, to delays incurred in the court proceedings. The recovery rate represents the part of the exposure that the creditor expects to recover on a given credit position, following the occurring of the default event;
4. Risk of exposure: this materialises in the possibility that the credit exposures increase just before the occurring of the debtor's default. Such situation may happen in the case of funding through bank account;

5. Country risk: this occurs when the State fails to meet its obligations; this may also be defined sovereign risk and can be due to politic or economic instability of the country itself.

On the basis of the previous considerations, a model able to correctly measure credit risk should rely on a distribution of events related to the exposure in which the default represents the extreme event, preceded by events that do not directly lead to default, but raise its probability.

The service of extending credit exposes the bank to potential partial or total loss of the lent capital, distinguished in Expected Loss (EL) and Unexpected Loss (UL).

The expected loss is linked to the events connected to the evolution of the debtor's financial conditions that the bank properly considered in its overdraft[27] decision and so evaluated as part of the pricing process, i.e. in the determination of the loan rate to be applied to the debtor. The expected loss is represented by the expected value of the losses' distribution; it must be estimated ex-ante from the bank and is covered by adding to the applied interest rate a spread in order to reach the target net return, assuming that the credit relationship evolves according to the expected scenario.

The unexpected loss is defined as the variability of the observed loss around its expected value; it is the additional loss beyond the expected loss and up to the loss percentile used for defining VaR. In the strict sense, the true component of the credit risk is represented by the possibility of the occurring of unexpected events leading to the deterioration of the credit quality or to the default of the debtor, therefore giving rise to losses that are not priced during the determination of the interest rate applied to the debtor. Unexpected loss does not include exceptional loss beyond the loss percentile defined by a given confidence level.

The exceptional loss is in excess of the sum of expected loss plus unexpected loss, which is equal to the loss percentile *L(a)*; its magnitude can be determined only in stress scenarios, in which all effects of extreme situations are considered. Analytically, expected and unexpected loss are quantified by the following relations:

$$EL = E[L] = PD \times LGD \times EAD$$

$$UL = Var(L) = EAD \times \sqrt{PD \times \sigma_{LGD}^2 + LGD^2 \times \sigma_{PD}^2}$$

where:

- L = Loss, it is a binary variable taking value $L = LGD \times EAD$ in case of default event and value 0 otherwise;

[27] An overdraft is an extension of credit from a lending institution that is granted when an account reaches zero.

- PD = Probability of Default, i.e. the probability of a debtor's default, assumed statistically independent of the severity of loss (LGD). Its variance is defined as $\sigma^2_{\text{PD}} = \text{PD} \times (1 - \text{PD})$;

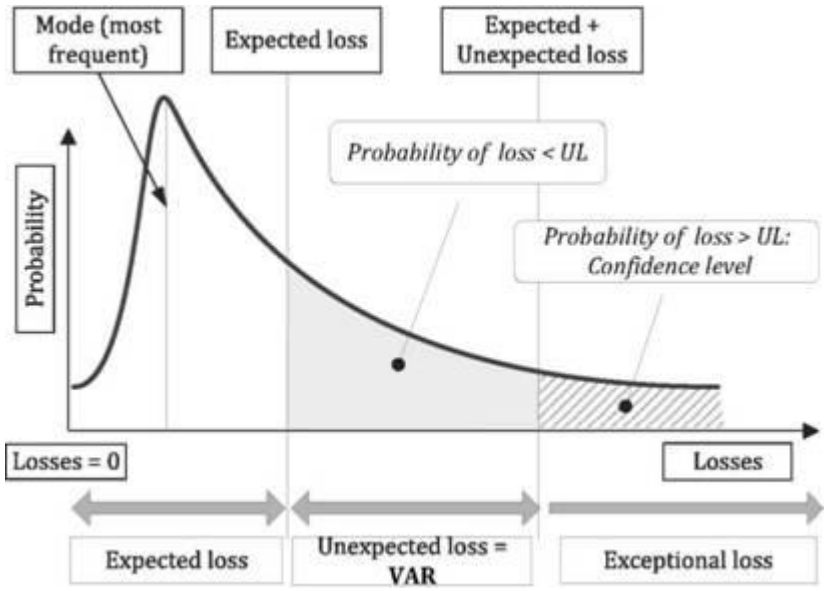
- LGD = Loss Given Default, i.e. the loss in case of default, it is equal to one minus the recovery rate: $\text{LGD} = 1 - \text{RR}$;

- EAD = Exposure at Default, i.e. the exposure at the time of a loan's default, assumed to be not random.

In Figure 5 the three measures appear. The distribution is asymmetric, with a fat tail extending to the right, and matches the general shape of portfolio losses for credit risk. Losses appear on the right-hand side of the zero level along the x-axis. The VaR at a given confidence level is a loss percentile in excess of expected loss (p_α); The area under the curve between EL and VaR value on the x-axis represents this probability. The maximum total loss at the same confidence level is the sum of the expected loss plus the unexpected loss (or loss percentile). Another measure to consider is the Economic Capital (EC), also said Capital at Risk or Credit-VaR. Analytically, it is given by the difference between the α-percentile of the loss distribution and the expected value for a given confidence level:

$$EC = p_\alpha - EL$$

Figure 5: Possible loss distribution for a credit portfolio



Source: Basel Committee on Banking Supervision (2005), An Explanatory Note on the Basel II Internal Rating Based Risk Weight Functions, BIS, Bank for International Settlements.

The distinction between expected and unexpected loss is of crucial importance in the risk management strategies. This is evident by considering a large institution's banking book[28], containing

[28] The banking book refers to assets on a bank's balance sheet that are expected to be held to maturity. Banks are not required to mark these to market. They are usually held at historical cost.

a great number of bank loans with extremely varied types of instruments and maturities. In fact, on one hand, the expected loss of such portfolio is computed as the sum of the expected loss for each bank loan, hence it is not diversifiable by nature; on the other hand, the unexpected loss is directly proportional to the degree of correlation among the bank loans and in theory it may be eliminated by connecting bank loans with negative correlation, thus it can be reduced and managed through an adequate diversification strategy of the bank loans. Another relevant concept is the fact that, while the bank is required to create and maintain provisions for facing the expected loss, which is estimated ex-ante, when it takes place, it has to find adequate coverage for the unexpected loss in its capital. Indeed, the rationale behind minimum capital requirements imposed by Basel rules is to ensure that banks have enough capital to absorb unexpected loss, proportionate to on and off-balance exposures (credit and market exposure) and to liquidity and operational risks.

3.2. Introduction to the Internal Ratings Based approach

In accordance with the Regulation (EU) No 575/2013, known as "Capital Requirements Regulation – CRR" and the provisions regarding the computation of the credit RWA, banks have to evaluate the credit quality of their current exposures in order to determine the associated risk weight. In addition to the standardised method, banks can use the IRB approach, through which they are required to analytically compute the three parameters on which the calculation formula of RWA, elaborated by Basel II, is based.

3.2.1. Elements of the IRB approach

Basel II comprehensive version describes for each of the asset classes covered four key elements under the IRB framework.

1. Categorisation of risk exposures: a classification of the exposures into classes according to their risk characteristics;
2. Risk components: the estimates of risk parameters provided by banks; some of them are, instead, supervisory estimates;
3. Risk-weight functions: the means by which risk components are transformed into risk-weighted assets and therefore capital requirements;
4. Minimum requirements: the minimum standards that a bank must fulfil in order to use the IRB approach for a given asset class.

The previous listed elements are described in more detail in the paragraphs below.

3.3. Credit risk exposures

Under the IRB approach, banks must categorise banking-book exposures into broad classes of assets with different underlying risk characteristics.

Corporate Exposures

In general, a corporate exposure is defined as a debt obligation of a corporation, partnership, or proprietorship. In addition to general corporates, within the corporate asset class, five sub-classes of specialised lending (SL) are identified. Such lending possesses all the following characteristics, either in legal form or economic substance:

- The exposure is typically to an entity (often a special purpose entity (SPE)) which was created specifically to finance and/or operate physical assets;
- The borrowing entity has little or no other material assets or activities, and therefore little or no independent capacity to repay the obligation, apart from the income that it receives from the assets being financed;
- The terms of the obligation give the lender a substantial degree of control over the assets and the income that it generates;
- As a result of the preceding factors, the primary source of repayment of the obligation is the income generated by the assets, rather than the independent capacity of a broader commercial enterprise.

The five sub-classes of specialised lending (SL) are project finance, object finance, commodities finance, income-producing real estate, and high-volatility commercial real estate.[29] Banks are permitted to distinguish separately exposures to small- and medium-sized entities (SME), defined as corporate exposures with annual sales of less than 50 Million Euros; this will allow banks to make use of a firm size adjustment to the corporate IRB risk weight.

Sovereign Exposures

This asset class covers exposures to sovereigns (and their central banks), certain public sector enterprises (PSEs) identified as sovereigns in the standardised approach and multilateral development banks (MDBs) that meet the criteria for a 0% risk weight under the standardised approach.

Bank Exposures

This asset class covers exposures to banks, securities firms, domestic PSEs that are treated like banks under the standardised approach and MDBs that do not meet the criteria for a 0% risk weight under the standardised approach.

Retail Exposures

An exposure is categorised as a retail exposure if it meets all of the following criteria:

- Nature of borrower or low value of individual exposures:

[29] BCBS (2017) paragraphs 8-10 defined corporate exposure.

- Exposures to individuals – such as revolving credits and lines of credit (e.g., credit cards, overdrafts, and retail facilities secured by financial instruments) as well as personal term loans and leases (e.g., instalment loans, auto loans and leases, student and educational loans, personal finance, and other exposures with similar characteristics) – are generally eligible for retail treatment regardless of exposure size, although supervisors may wish to establish exposure thresholds to distinguish between retail and corporate exposures;
- Residential mortgage loans (including first and subsequent liens, term loans and revolving home equity lines of credit) are eligible for retail treatment regardless of exposure size so long as the credit is: i) an exposure to an individual[30]; or ii) an exposure to associations or cooperatives of individuals that are regulated under national law and exist with the only purpose of granting its members the use of a primary residence in the property securing the loan;
- Loans extended to small businesses and managed as retail exposures are eligible for retail treatment provided the total exposure of the banking group to a small business borrower (on a consolidated basis where applicable) is less than €1 million. Small business loans extended through or guaranteed by an individual are subject to the same exposure threshold;

- Large number of exposures: the exposure must be one of a large pool of exposures, which are managed by the bank on a pooled basis. Small business exposures below €1 million may be treated as retail exposures if the bank treats such exposures in its internal risk management systems consistently over time and in the same manner as other retail exposures. This requires that such an exposure be originated in a similar manner to other retail exposures. Furthermore, it must not be managed individually in a way comparable to corporate exposures, but rather as part of a portfolio segment or pool of exposures with similar risk characteristics for purposes of risk assessment and quantification. However, this does not preclude retail exposures from being treated individually at some stages of the risk management process. The fact that an exposure is rated individually does not by itself deny the eligibility as a retail exposure.

Within the retail asset class category, banks are required to identify separately three sub-classes of exposures: residential mortgage loans, described above, qualifying revolving retail exposures, as defined in the next point, and all other retail exposures.

Qualifying revolving retail exposures

All of the following criteria must be satisfied for a sub-portfolio to be treated as a qualifying revolving retail exposure (QRRE). These criteria must be applied at a sub-portfolio level consistent with the bank's segmentation of its retail activities generally. Segmentation at the national or country level (or below) should be the general rule.

- The exposures are revolving, unsecured, and uncommitted (both contractually and in practice). In this context, revolving exposures are defined as those where customers' outstanding balances

[30] At national discretion, supervisors may exclude from the retail residential mortgage sub-asset class loans to individuals that have mortgaged more than a specified number of properties or housing units, and treat such loans as corporate exposures.

are permitted to fluctuate based on their decisions to borrow and repay, up to a limit established by the bank;

- The exposures are to individuals;
- The maximum exposure to a single individual in the sub-portfolio is €100,000 or less;
- Because the asset correlation assumptions for the QRRE risk-weight function are markedly below those for the other retail risk-weight function at low PD values, banks must demonstrate that the use of the QRRE risk-weight function is constrained to portfolios that have exhibited low volatility of loss rates, relative to their average level of loss rates;
- Data on loss rates for the sub-portfolio must be retained in order to allow analysis of the volatility of loss rates;
- The supervisor must concur that treatment as a qualifying revolving retail exposure is consistent with the underlying risk characteristics of the sub-portfolio.[31]

In the Retail category there is no distinction between Foundation and Advanced IRB approaches because in both methods banks have to provide own estimates of PD, LGD and EAD.

Equity Exposures

Equity exposures include both direct and indirect ownership interests, whether voting or non-voting, in the assets and income of a commercial enterprise or of a financial institution. An instrument is considered to be an equity exposure if it meets all of the following requirements:

- It is irredeemable in the sense that the return of invested funds can be achieved only by the sale of the investment or sale of the rights to the investment or by the liquidation of the issuer;
- It does not embody an obligation on the part of the issuer;
- It conveys a residual claim on the assets or income of the issuer.

The following discussion will be limited only to corporate, sovereign, bank and retail exposures.

3.4. Risk components

Probability of Default (PD)

The probability of default (PD), measures the likelihood that the borrower will default over a given time horizon. All banks whether using the foundation or the advanced methodology have to provide an internal estimate of the PD associated with the borrowers in each borrower grade. Each estimate of PD has to represent a conservative view of a long-run average PD for the grade in question and has to be grounded in historical experience and empirical evidence. The preparation of the estimates, the risk management processes, and the rating assignments that lay behind them have to reflect full compliance with supervisory minimum requirements to qualify for the IRB recognition. For corporate, sovereign and bank exposures, the PD is the one-year PD associated with the internal borrower grade to which that exposure is assigned. The PD of borrowers assigned to a default grade,

[31] BCBS (2017) paragraphs 21-25 defined retail exposure.

consistent with the reference definition of default, is 100%. The PD for each exposure that is used as input into the risk weight formula and the calculation of expected loss must not be less than 0.05%.[32] The PD for retail exposures is the greater of: i) the one-year PD associated with the internal borrower grade to which the pool of retail exposures is assigned; and ii) 0.1% for QRRE revolvers and 0.05% for all other exposures.[33] One-year PD must be estimated using at least 5 years of data.

Loss Given Default (LGD)

The loss-given-default (LGD) measures the proportion of the exposure that will be lost if default occurs. While PD is associated with a given borrower and, consequently, does not depend on the features of the specific transaction, LGD is facility-specific. The LGD value can be determined in two ways. According to the foundation methodology, LGD is estimated through the application of standard supervisory rules. Under the foundation approach, corporate, sovereign and bank exposures not secured by recognised collateral are assigned a 45% LGD, while corporate, sovereign and bank subordinated exposures[34] are assigned a 75% LGD[35]. According to the advanced methodology, the bank itself determines appropriate LGD to be applied to each exposure, on the basis of robust data and analysis which is capable of being validated both internally and by supervisors. Thus, a bank using internal LGD estimates for capital purpose might be able to differentiate LGD value on the basis of a wider set of borrower characteristics. Under the advanced approach, LGD must be measured as a percentage of the EAD. For unsecured corporate, sovereign and exposures LGD cannot be less than 25%, while for secured corporate, sovereign and bank exposures the LGD minimum value ranges from 0% to 15% depending on the type of collateral.[36] For unsecured retail exposures the LGD minimum value ranges from 0% to 30% depending on the type of sub-class, while for secured retail exposures the LGD minimum value ranges from 0% to 15% depending on the type of sub-class and the type of collateral[37].

Exposure at Default (EAD)

The exposure at default includes the on-balance sheet exposures and an estimate of the off-balance sheet ones. As with LGD, EAD is also facility specific. Under Basel IRB guidelines, EAD and LGD are inter-related; LGD is in fact measured as a percentage loss relative to EAD. All exposures are measured gross of specific provisions or partial write-offs. The EAD on drawn amounts should not

[32] BCBS (2017) paragraphs 67-68.

[33] BCBS (2017) paragraph 121.

[34] A subordinated loan is a facility that is expressly subordinated to another facility.

[35] BCBS (2017) paragraphs 70-71.

[36] BCBS (2017) paragraphs 84-85.

[37] BCBS (2017) paragraph 121.

be less than the sum of the amount by which a bank's regulatory capital would be reduced if the exposure were written-off fully and any specific provisions and partial write-offs.[38] The EAD value can be determined in two ways. Under the foundation approach, EAD is calculated as the committed but undrawn amount multiplied by a CCF, ex-ante determined by the supervisory authority. In the advanced approach, EAD for undrawn revolving commitments[39] may be calculated as the committed but undrawn amount multiplied by an internal estimated CCF or derived from direct estimates of total facility EAD. Banks are allowed to use their own internal estimates of EAD provided the exposure is not subject to a CCF of 100% in the foundation approach.[40] Credit conversion factor (CCF) for revolving lines of credit is the ratio of the estimated additional drawn amount during the period up to 12 months before default over the undrawn amount at the time of estimation.

Maturity (M)

The maturity of the exposure measures the remaining economic maturity of the asset. For banks using the foundation approach for corporate exposures, effective maturity (M) will be 2.5 years. Banks using the advanced approach are required to measure effective maturity for each facility. The effective maturity is subject to a floor of one year and a cap of 5 years. For an instrument subject to a determined cash flow schedule, effective maturity is defined as:

$$M = \frac{\sum_t t \times CF_t}{\sum_t CF_t}$$

where CF_t denotes the cashflows (principal, interest payments and fees) contractually payable by the borrower in period t.

If a bank is not in a position to calculate the effective maturity of the contracted payments as noted above, it is allowed to use a more conservative measure of M such as that it equals the maximum remaining time (in years) that the borrower is permitted to take to fully discharge its contractual obligation (principal, interest, and fees) under the terms of loan agreement. Normally, this will correspond to the nominal maturity of the instrument.[41]

[38] BCBS (2017) paragraphs 98 and 124.

[39] A revolving loan facility is one that lets a borrower obtain a loan where the borrower has the flexibility to decide how often to withdraw from the loan and at what time intervals. A revolving facility allows the borrower to drawdown, repay and re-draw loans advanced to it. Facilities that allow prepayments and subsequent redraws of those prepayments are considered as revolving.

[40] BCBS (2017) paragraphs 105 and 125.

[41] BCBS (2017) paragraphs 107-109.

3.5. Risk–weighted–assets

Risk–weighted–assets for corporate, sovereign and bank exposures

The derivation of risk-weighted assets is dependent on estimates of the PD, LGD, EAD and, in some cases, effective maturity (M), for a given exposure. PD and LGD are measured as decimals, and EAD is measured as currency (e.g., Euro). For exposures not in default, the formula for calculating risk-weighted assets is:

$$Risk\ Weighted\ Assets\ (RWA) = K \times 12.5 \times EAD$$

where K represent the capital requirement and is computed as follows:

$$Capital\ Requirement\ (K) = \left[LGD \times N\left[\frac{G(PD)}{\sqrt{1-R}} + \sqrt{\frac{R}{1-R}} \times G(0.999)\right] - PD \times LGD\right] \times \frac{(1 + (M + 2.5) \times b)}{(1 - 1.5 \times b)}$$

where:

- $Correlation\ (R) = 0.12 \times \frac{(1-e^{-50\times PD})}{(1-e^{-50})} + 0.24\left(1 - \frac{(1-e^{-50\times PD})}{(1-e^{-50})}\right)$;

- $Maturity\ adjustment\ (b) = [0.11852 - 0.05478 \times \ln(PD)]^2$;

- N(x) denotes the cumulative distribution function for a standard normal random variable (i.e. the probability that a normal random variable with mean zero and variance of one is less than or equal to x). G(z) denotes the inverse cumulative distribution function for a standard normal random variable (i.e. the value of x such that N(x) = z);

- ln denotes the natural logarithm.

If the calculation of K results in a negative capital charge for any individual sovereign exposure, banks should apply a zero-capital charge for that exposure.

Formally speaking, the formula is based on a one-factor model, meaning that there is only one systematic factor as a proxy for general economic conditions that drives correlations across borrowers. This is important because it gives rise to additive, portfolio-invariant contributions to capital, i.e. the IRB capital requirements only depend on each individual loan's own characteristics and do not have to be calibrated for each portfolio based on its particular composition. A common characteristic is that lower quality (higher PD) assets have lower correlations. This corresponds to the empirical finding that lower quality exposures are driven mainly by idiosyncratic (borrower-specific) factors and thus relatively less by broader market events (systematic risk).

The capital requirement (K) for a defaulted exposure is equal to the greater of zero and the difference between its LGD and the bank's best estimate of expected loss. The risk-weighted asset amount for the defaulted exposure is the product of K, 12.5, and the EAD[42].

Firm-size adjustment for small- and medium-sized entities (SME)

Under the IRB approach for corporate credits, banks will be permitted to separately distinguish exposures to SME borrowers (defined as corporate exposures where the reported sales for the consolidated group of which the firm is a part is less than €50 million) from those to large firms. A firm-size adjustment $\left(i.e.\, 0.04 \times \left(\frac{1-(S-5)}{45}\right)\right)$ is made to the corporate risk weight formula for exposures to SME borrowers. S is expressed as total annual sales in millions of euros with values of S falling in the range of $€5\ million \leq S \leq €50\ million$. Reported sales of less than €5 million will be treated as if they were equivalent to €5 million for the purposes of the firm-size adjustment for SME borrowers.

$$Correlation\ (R) = 0.12 \times \frac{(1-e^{-50\times PD})}{(1-e^{-50})} + 0.24\left(1 - \frac{(1-e^{-50\times PD})}{(1-e^{-50})}\right) - \ 0.04 \times \left(\frac{1-(S-5)}{45}\right)$$

Subject to national discretion, supervisors may allow banks, as a failsafe, to substitute total assets of the consolidated group for total sales in calculating the SME threshold and the firm-size adjustment. However, total assets should be used only when total sales are not a meaningful indicator of firm size.[43]

Risk–weighted–assets for retail exposures

There are three separate risk-weight functions for retail exposures. None of the three retail risk-weight functions contain the full maturity adjustment component that is present in the risk-weight function for exposures to banks and corporates. PD and LGD are measured as decimals, and EAD is measured as currency (e.g., Euro).

Retail residential mortgage exposures

For exposures that are not in default and are secured or partly secured by residential mortgages, risk weights will be assigned based on the following formula:

$$Risk\ Weighted\ Assets\ (RWA) = K \times 12.5 \times EAD$$

where K represent the capital requirement and is computed as follows:

[42] BCBS (2017) paragraphs 52-53.

[43] BCBS (2017) paragraph 54.

$$Capital\ Requirement\ (K) = \left[LGD \times N \left[\frac{G(PD)}{\sqrt{1-R}} + \sqrt{\frac{R}{1-R}} \times G(0.999) \right] - PD \times LGD \right]$$

where:

- $Correlation\ (R) = 0.15$

The capital requirement (K) for a defaulted exposure is equal to the greater of zero and the difference between its LGD and the bank's best estimate of expected loss. The risk-weighted asset amount for the defaulted exposure is the product of K, 12.5 and the EAD.

Qualifying revolving retail exposures

For qualifying revolving retail exposures that are not in default, risk weights are defined based on the following formula:

$$Risk\ Weighted\ Assets\ (RWA) = K \times 12.5 \times EAD$$

where K represent the capital requirement and is computed as follows:

$$Capital\ Requirement\ (K) = \left[LGD \times N \left[\frac{G(PD)}{\sqrt{1-R}} + \sqrt{\frac{R}{1-R}} \times G(0.999) \right] - PD \times LGD \right]$$

where:

- $Correlation\ (R) = 0.04$

The capital requirement (K) for a defaulted exposure is equal to the greater of zero and the difference between its LGD and the bank's best estimate of expected loss. The risk-weighted asset amount for the defaulted exposure is the product of K, 12.5, and the EAD.

Other retail exposures

For all other retail exposures that are not in default, risk weights are assigned based on the following function, which allows correlation to vary with PD:

$$Risk\ Weighted\ Assets\ (RWA) = K \times 12.5 \times EAD$$

where K represent the capital requirement and is computed as follows:

$$Capital\ Requirement\ (K) = \left[LGD \times N \left[\frac{G(PD)}{\sqrt{1-R}} + \sqrt{\frac{R}{1-R}} \times G(0.999) \right] - PD \times LGD \right]$$

where:

$$- Correlation\ (R) = 0.03 \times \frac{(1-e^{-35\times PD})}{(1-e^{-35})} + 0.16\left(1 - \frac{(1-e^{-35\times PD})}{(1-e^{-35})}\right)$$

The capital requirement (K) for a defaulted exposure is equal to the greater of zero and the difference between its LGD and the bank's best estimate of expected loss. The risk-weighted asset amount for the defaulted exposure is the product of K, 12.5, and the EAD[44].

3.6. Minimum requirements for IRB approach

The implementation of IRB methodologies by the banks requires regulatory approval. Therefore, in order to qualify for the IRB approach, banks must meet a stringent list of requirements, which are aimed at pursuing regulators' objectives and concern 12 separate sections.

Composition of minimum requirements

The general principle behind the minimum requirements is that rating and risk estimation systems and processes must provide for:

- A meaningful assessment of borrower and transaction characteristics;
- A meaningful differentiation of risk;
- Reasonably accurate and consistent quantitative estimates of risk.

Furthermore, the systems and processes must be consistent with internal use of these estimates. The minimum requirements apply to all asset classes, to both foundation and advanced approach.

Compliance with minimum requirements

In order to be eligible for an IRB approach, a bank must demonstrate to its supervisor that it meets the IRB requirements both at the beginning and on an ongoing basis. There may be circumstances when a bank is not in complete compliance with all the minimum requirements. In such cases, the bank must produce a plan for a timely return to compliance and seek approval from its supervisor, or it must demonstrate that the effect of such non-compliance is immaterial in terms of the risk posed to the institution. Failure to produce an acceptable plan/satisfactorily implement the plan or to demonstrate immateriality will lead supervisors to reconsider the bank's eligibility for the IRB approach. Furthermore, for the duration of any non-compliance, supervisors may require the bank to hold additional capital or take other appropriate supervisory action.

Rating system design

The term "rating system" comprises all of the methods, processes, controls, and data collection and IT systems that support the assessment of credit risk, the assignment of internal risk ratings, and the

[44] BCBS (2017) paragraphs 117-120.

quantification of default and loss estimates. Within each asset class, a bank may use multiple rating systems; however, if this is the case, the methodology for assigning a borrower to a rating system must be logical and documented. Moreover, banks must not allocate borrowers across rating systems inappropriately to minimise regulatory capital requirements.

A qualifying IRB rating system must have two separate and distinct dimensions:

- Borrower characteristics indicating the risk of borrower default;
- Transaction-specific factors such as collateral, seniority, product type, etc.

A borrower grade is defined as an assessment of borrower risk on the basis of a specified and distinct set of rating criteria, from which estimates of PD are derived. A bank must have a meaningful distribution of exposures across grades with no excessive concentration of borrowers in one particular grade. To meet this objective, a bank must have a minimum of seven borrower grades for non-defaulted borrowers and one for those that have defaulted.

A bank must have specific rating definitions, processes and criteria for assigning exposures to grades within a rating system. Written rating definitions must be clear and detailed enough to allow third parties (e.g., internal audit or an equally independent function and supervisors) to understand the assignment of ratings, to replicate rating assignments and evaluate the appropriateness of the grade/pool assignments. Banks must use all relevant and material information in assigning ratings to borrowers and facilities.

Although the time horizon used in PD estimation is one year, banks are expected to use a longer time horizon in assigning ratings. A borrower rating must, in fact, represent the bank's assessment of the borrower's ability and willingness to contractually perform despite adverse economic conditions or the occurrence of unexpected events. Given the difficulties in forecasting future events and the influence they will have on a particular borrower's financial condition, a bank must take a conservative view of projected information, especially when limited data are available.

Credit scoring models can play a role in the estimation of loss characteristics as long as sufficient human judgement is considered to ensure that all relevant and material information is taken into consideration, and that the model is used appropriately. The bank must demonstrate that a model has good predictive power and that regulatory capital requirements will not be distorted as a result of its use. It must also prove that the data used to build the model are representative of the population of the bank's actual borrowers or facilities. The bank must have a regular cycle of model validation that includes monitoring of model performance and stability; review of model relationships; and testing of model outputs against outcomes.

Banks must document in writing their rating systems' design and operational details.

Risk rating system operations

For corporate, sovereign and bank exposures, each borrower must be assigned a rating and each exposure must be associated with a facility rating as part of the loan approval process. Similarly, for retail, each exposure must be assigned to a pool as part of the loan approval process.

Rating assignments and periodic rating reviews must be completed or approved by a party that does not directly benefit from the extension of credit. Borrowers and facilities must have their ratings refreshed at least on an annual basis.

A bank must collect and store data on key borrower and facility characteristics to provide effective support to its internal credit risk measurement and management process and to serve as a basis for supervisory reporting. These data should be sufficiently detailed to allow retrospective re-allocation of obligors and facilities to grades.

An IRB bank must have in place sound stress testing processes for the assessment of capital adequacy. Stress testing must involve identifying possible events or future changes in economic conditions that could have unfavourable effects on a bank's credit exposures and assessment of the bank's ability to withstand such changes. Examples of scenarios that could be used are economic or industry downturns, market-risk events, and liquidity conditions.

Corporate governance and oversight

All material aspects of the rating and estimation processes must be approved by the bank's board of directors and senior management, who must possess a general understanding of the bank's risk rating system and its associated management reports. Management must also ensure, on an ongoing basis, that the rating system is operating properly and must identify areas needing improvement.

Reporting must include:

- Risk profile by grade;
- Migration across grades;
- Estimation of the relevant parameters per grade;
- Comparison of realised default rates (and LGDs and EADs for banks on advanced approaches) against expectations.

Banks must have independent credit risk control units that are responsible for the design or selection, implementation and performance of their internal rating systems. Internal audit or an equally independent function must review at least annually the bank's rating system and its operations and document its findings.

Use of internal ratings

Internal ratings and default and loss estimates must play an essential role in the credit approval, risk management, internal capital allocations, and corporate governance functions of banks using the IRB approach. Ratings systems and estimates designed and implemented exclusively for the purpose of qualifying for the IRB approach and calculating regulatory capital are not acceptable.

A bank must have a credible track record in the use of internal ratings information. Thus, the bank must demonstrate that it has been using a rating system that was broadly in line with the minimum requirements for at least the three years prior to qualification.

Risk quantification

Overall requirements for estimation include the following:

- PD estimates must be a long-run average of one-year default rates for borrowers in the grade, with the exception of retail exposures;
- For exposures subject to the advanced approach, banks must also estimate an appropriate long-run default-weighted average EAD for each of its facilities;
- Internal estimates of PD, LGD, and EAD must incorporate all relevant, material and available data, information and methods;
- Estimates must be grounded in historical experience and empirical evidence, and not based purely on subjective or judgmental considerations;
- In order to avoid over-optimism, a bank must add to its estimates of PDs, LGDs, and EADs a margin of conservatism that is related to the likely range of errors.

A default is considered to have occurred with regard to a particular obligor when either or both of the two following events have taken place:

- The bank considers that the obligor is unlikely to pay its credit obligations to the banking group in full;
- The obligor is past due more than 90 days on any material credit obligation to the banking group. Overdrafts will be considered as being past due once the customer has breached an advised limit.

The definition of loss used in estimating LGD is economic loss, not accounting loss. When measuring economic loss, all relevant factors, including material discount effects and material direct and indirect costs associated with collecting on the exposure, should be taken into account.

Important considerations in quantifying risk parameters include:

- PD estimates may be derived based on one or more of the following techniques - internal default experience, mapping to external data, statistical default models;
- For retail exposures, the primary driver of PD estimates must be internal data;
- LGD estimates should be based on economic downturn conditions;

- LGD estimates should be based on historical recoveries as well as any existing collateral;
- For exposures already in default, LGD should be estimated as the best estimate of expected loss on the asset considering the current economic climate;
- For closed-end exposures, EAD must not be lower than the current outstanding balance owed to the bank;
- For corporate, sovereign or bank exposures, LGD and EAD estimates should be based on a full economic cycle and must not be shorter than a period of seven years;
- For retail exposures, the estimates should be based on minimum five years of data unless the bank can demonstrate that recent data is a better predictor of the estimates.

Validation of internal estimates

Banks must have a robust system in place to validate the accuracy and consistency of rating systems, processes, and the estimation of all relevant risk components.

Banks must regularly compare realised default rates with estimated PDs for each grade and be able to demonstrate that the realised default rates are within the expected range for that grade. Banks using the advanced IRB approach must complete such analysis for their estimates of LGDs and EADs. Such comparisons must make use of historical data that are over as long a period as possible.

Banks must demonstrate that quantitative testing methods and other validation methods do not vary systematically with the economic cycle.

Supervisory LGD and EAD estimates

Banks under the foundation IRB approach, which do not meet the requirements for own-estimates of LGD and EAD, must meet the minimum requirements of the standardised approach to receive recognition for eligible financial collateral.

Requirements for recognition of leasing

Leases other than those that expose the bank to residual value risk will be accorded the same treatment as exposures collateralised by the same type of collateral. Residual value risk is the bank's exposure to potential loss due to the fair value of the equipment declining below its residual estimate at lease inception.

Calculation of capital charges for equity exposures

Basel Accord defines the capital charge for equity exposures as follows - The capital charge is equivalent to the potential loss on the institution's equity portfolio arising from an assumed instantaneous shock equivalent to the 99th percentile, one-tailed confidence interval of the difference between quarterly returns and an appropriate risk-free rate computed over a long-term sample period.

The following further requirements must be met by banks in order to calculate minimum capital charges under the internal models approach:

- Estimated losses should be based on sound statistical judgment and should be stable under adverse market movements;
- Models should be adjusted to demonstrate that it provides a conservative estimate of long-run loss experience;
- The Accord does not require the use of a particular kind of model but requires that all risk be embedded in the process;
- Stress testing taking into account various assumptions on volatility and hypothetical scenarios should be conducted;
- The models should be integrated into the risk management process; including setting hurdle rates and evaluating risk-adjusted performance;
- The models must be regularly monitored by an independent team and all assumptions verified.

Disclosure requirements

In order to be eligible for the IRB approach, banks must meet the disclosure requirements set out in Pillar 3. Failure to meet these requirements will render banks ineligible to use the relevant IRB approach.[45]

[45] BCBS (2017) paragraphs 154-300.

CHAPTER 4 – REVIEW OF THE MANAGEMENT OF IRB DATA

4.1. Introduction to the Targeted Review of Internal Models (TRIM)

4.1.1. Reasons underlying the project

Following the financial crisis, there has been much debate about the use of internal models to determine own funds requirements, mainly because of two reasons:

a. Internal models have become more complex since they were first introduced under Basel II. This has made it increasingly difficult for banks and supervisors to assess whether risks are being mapped correctly and consistently;
b. A number of benchmarking studies have highlighted potential inconsistencies as well as high variability in own funds requirements that different banks with similar portfolios have calculated using internal models.

Regarding the first point, these last years, internal models have been under pressure as financial markets and supervisors claim to have lost confidence that banks are fully equipped to adequately assess their risk exposure and the corresponding required capital. Several studies have exposed unwarranted variability in RWA. This variability can be explained by all stages of the modelling and reporting process due to a lack of independence of (validation) functions, outdated and incomplete data and IT systems, variations and inconsistencies in key regulatory definitions and general methodological differences.

Focusing particularly on the second point, the fundamental problem is that the choice whether to use the standardised approach or the internal models one seems to be mainly based on which method requires the least capital rather than the most appropriate level of capital for the risk a firm is taking. Several analyses performed by the European Banking Authority (EBA) showed the downside of using the internal models, that is the possibility for big banks to reduce the amount of capital needed; in fact, the high discretion characterising such approach would allow institutions to manipulate the risk coefficients and so to benefit from unjustified savings in the capital required, ensuring in this way a competitive advantage to the banks authorised to use their internal models. According to regulators a majority of banks using the internal model approach would have to hold a bigger amount of capital if they used the standardised models as most smaller lenders. Since an incorrect use of these models by numerous banks might cause an imbalance in the whole banking system, the problems cannot be limited to the technical aspects. Specifically, banks with lower capital requirements take more advantage of this discretion in the computation of risk parameters, becoming able to grant higher credit at rates lower than the average.

4.1.2. Targeted Review of Internal Models' objectives and structure

As a response to these problems, the ECB, in close cooperation with the national competent authorities that are part of the Single Supervisory Mechanism (SSM), launched the Targeted Review of Internal Models, or TRIM, which is a multi-year project to assess whether the internal models

currently used by significant institutions in the SSM comply with regulatory requirements, and whether their results are reliable and comparable, enhancing in this way the credibility of the internal models being used by banks subject to European banking supervision. Banks can use internal models to determine their Pillar 1 own funds requirements, i.e. the minimum amount of capital they must hold by law.

One major objective of TRIM is to reduce inconsistencies and unwarranted variability when banks use internal models to calculate their own funds requirements. TRIM also seeks to ensure consistent supervisory practices. As a result, the review should help to make sure that internal models are being used appropriately and consistently. The objectives of TRIM are therefore in line with two major goals of ECB Banking Supervision: to foster a sound and resilient banking system through proactive supervision and the use of best practices and to ensure that supervisory practices are applied consistently across the euro area.

Under the project, the ECB is currently checking Pillar 1 approved models at all directly supervised banks that use them. However, not all approved models at all banks are being checked and there are a few other exceptions, e.g. banks undergoing a merger or those which may no longer be subject to direct supervision. This means that about 65 significant institutions across the SSM fall within the scope of TRIM. The project covers credit, market and counterparty credit risk (operational risk has been excluded given the Basel Committee on Banking Supervision's stance against using internal models for such risk). Counterparty credit risk is defined as the risk arising from the possibility that the counterparty may default on amounts owned on a derivative transaction.

In December 2015 the ECB decided that it would carry out a targeted review of internal models. The TRIM project is organized in different steps.

1. First step: The initial preparatory work to identify the underlying methodology and tools and the models to be reviewed took place in 2016. In order to establish a common, standardised and methodological procedure for the on-site investigations, the ECB published a guide which laid out the framework to follow. The key objective was to be transparent and clear on how the ECB understood the regulatory requirements and how it would have controlled that all banks met these requirements. Common inspection techniques and tools were established as well as pre-defined areas of investigation. Moreover, to ensure that the inspection techniques and tools were applied consistently, a close interaction between the assessment teams and the risk-specific team was required during the on-site investigation;
2. Second step: TRIM on-site investigations started in 2017. Further on-site investigations took place in 2018 and continued in 2019. In total, 200 on-site investigations were launched since the beginning of the project and the on-site phase was concluded for all of them. Each on-site mission was staffed by at least six people, belonging to the JST, and lasted over a period of at least ten weeks. This stage of the quality assurance consisted in checking the reports produced by the assessment teams to ensure that similar shortcomings gave rise to similar findings. The check was done by internal models' experts from different National Competent Authorities (NCA) and the ECB, who have a horizontal view of the TRIM investigations for each risk type;

3. Third step: The final step involves follow-up decisions based on the findings of each on-site investigation. Every decision that is taken must be supported by regular exchange and alignment sessions for the model experts, which have access to a comprehensive overview of past cases. These decisions are also challenged and reviewed within the ECB before being sent to the banks.

To better understand the phases and the related activities of the project, its timeline is showed below.

Figure 6: TRIM timelines and activities

	Preparatory Phase	Targeted Review Phase	Follow-up
	2016	On-site inspections in 2017 - 2018 - 2019	After 2018
Objective	• Selection of models • Create review handbooks	• On-site in-depth model reviews • Horizontal reviews of selected models	• Remediation and monitoring of findings
ECB	• Prepare and conduct surveys • On-site interviews and collection documentation • Define model selection criteria • Prepare model review methodology • Finalise selection of models	• Review of IT and data quality • Collect and process data • On-site in-depth methodological review per portfolio • Horizontal review and benchmarking	• Communicate findings of Targeted Review Phase • Monitoring of findings • Identify new guidance
Banks	• General preparation for TRIM based on ECB documents e.g. Regulatory Technical Standards • Perform quick fixes and create model development planning • Set up response team	High availability of internal stakeholders expected • Supply all model documents • Provide all relevant policies • Demonstrate model use • Delivery of high data quality • Q&A sessions	Remediate findings possibly covering: • Model methodology • Model governance & organisation • Processes & use test • Data and IT systems

Source: Accenture

Before starting the execution phase, a review of the general conditions for the use of internal models was carried out. The subsequent execution phase can be divided into two key parts:

1. Part one: this involved a review of the models used to assess the credit risk for retail and small and medium-sized enterprise portfolios, as well as market risk and counterparty credit risk; on-site investigations were conducted in 2017 and in the first half of 2018;
2. Part two: this is still ongoing and mainly focuses on the models used to assess the credit risk for so-called low-default portfolios (these cover exposures to medium-sized/large corporates and institutions, as well as specialised lending); it started in the second half of 2018 and is continuing in 2019.

Among the many expectations underlying the launching of the TRIM project, the most relevant are the following: demonstrate regulatory compliance with the model framework, including compliance to EBA Consultation Paper on estimation of PD and LGD; produce evidence of adequate model validation processes; show policies and procedures for model governance and data systems, including audit trails.

TRIM already had a significant impact on the financial sector and is expected to have consequences beyond 2019. From the perspective of the supervisors, TRIM allowed ECB to identify best practices resulting in new minimum standards; in addition to this, the structured investigation framework developed for TRIM and the in-depth knowledge gained during the exercise will also establish high

standards for future internal model supervision and help ensure the application of consistent supervisory practices across constituencies. TRIM results may also trigger new regulatory requirements. From the perspective of banks, banks will have to update their internal model approaches based on the review, especially banks that are outliers in peer analyses. TRIM could also lead to increases or decreases in the own funds needs of individual banks, even though the project aims to reduce unwarranted variability in own funds requirements across banks, not to increase own funds requirements in general.

Following the approach adopted earlier, the discussion will focus only on the outcomes of the general topics and credit risk review.

4.1.3. Outcome of TRIM investigations – General topics

The purpose of the general topics review was to consistently assess the institutions' positioning with regard to non-model-specific topics of the existing legal framework for internal models, with a particular focus on internal ratings-based (IRB) models. In particular, the topics assessed in the review were the following:

- Overarching principles for internal models: principles for internal models subject to supervisory approval for the calculation of own funds requirements for credit, market and counterparty credit risk (Pillar 1 models);
- Roll-out and permanent partial use: application and roll-out of the IRB approach to the proposed asset classes;
- Internal governance: topic encompassing: i) the management body and senior management (i.e., decision-making responsibilities, internal reporting and understanding of the rating systems); ii) composition and independence of the credit risk control unit (CRCU); iii) governance of rating system information;
- Internal validation: function performing a consistent and meaningful assessment of the performance of internal rating and risk estimation systems;
- Internal audit: unit reviewing the institution's rating systems and its operations at least annually;
- Model use: the degree of use of risk parameters, together with the forms (adjusted/indirect) in which they are used;
- Management of changes to the IRB approach: changes to a rating system's range of application or to a rating system itself subject to approval by the competent authorities if assessed as material, or to ex ante or ex post notification if non-material;
- Third-party involvement: involvement of third parties in any IRB-related tasks, including data provisioning and the use of external data.

The review of the above topics started in the summer of 2016, with a comprehensive standardised request for information and documentation addressed to in-scope institutions. The off-site analysis of the information received was complemented and refined through short supervisory visits to the institutions' premises, carried out before the start of the execution phase of TRIM. On that basis, further horizontal analyses to ensure a consistent follow-up on potential issues detected were

conducted. The supervisory follow-up to the general topics review was dual. On the one hand, cases of total non-compliance with the applicable regulation were addressed through supervisory decisions that imposed obligations on the affected institutions to remediate the shortcomings within certain deadlines (see Table 4 for examples). On the other hand, additional potential misalignments with further aspects of the regulatory framework were communicated to the institutions via follow-up letters. Institutions were asked to respond to these letters by providing the Joint Supervisory Teams (JSTs) with written feedback on the current status of each issue.

Table 4: General topics review - examples of non-compliance cases

Description of shortcomings	Share of institutions with obligations[46]
Absence of a model change policy at the institution or absence of notification of material model changes to the competent authority	29%
Lack of evidence of annual back-testing for some rating systems	24%
Use of the standardised approach without formal authorisation of a permanent partial use (PPU)	19%
No strict separation of staff performing validation activities and staff involved in tasks of the credit risk control function (e.g. model development and monitoring)	19%
Current resources allocated to the internal validation function preventing a robust validation process	14%

Source: European Central Bank (2019), Second update on TRIM outcomes.

4.1.4. Outcome of TRIM investigations – Credit risk

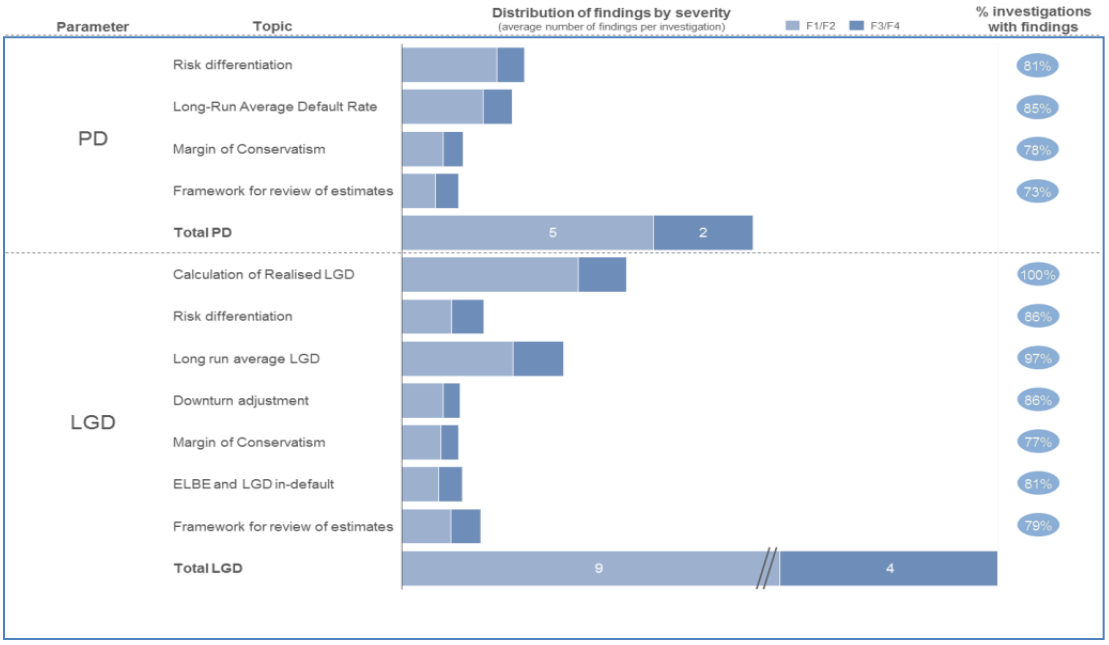
Credit risk models

The TRIM credit risk review consistently assessed the institutions' modelling practices for the relevant risk parameters (i.e., PD, LGD and CCF), with respect to a number of predefined methodological aspects that had been identified in the preparatory phase of TRIM as potential drivers of RWA variability. TRIM investigations first focused on credit risk models related to the exposure classes Retail and Corporate – SME ("retail and SME models"). Investigations on those models were mostly completed by end-June 2018. After the completion of the on-site phase, each TRIM draft assessment report underwent consistency checks to ensure a harmonised approach across investigations and a consistent application of the methodology and techniques. Cases of non-compliance with the CRR identified in each investigation have been addressed via dedicated supervisory decisions, and institutions have been asked to deal with these findings. Furthermore, the ECB also provided recommendations with a view to supporting future compliance with upcoming legal requirements and further specifications added to existing requirements.

[46] Out of the 21 institutions that received a dedicated supervisory decision on general topics.

Figure 7 provides an overview of the findings identified for PD and LGD in TRIM investigations on retail and SME models (around 80 investigations). With the purpose of making the representation clearer, the findings are categorised according to the relevant risk parameter and the related sub-topics. The chart provides an indication of the number of findings raised per topic, with a breakdown by severity, as well as the percentage of investigations for which at least one finding on the respective topic has been raised.

Figure 7: Credit risk models review – examples of findings



Source: European Central Bank (2019), Second update on TRIM outcomes.

Regarding the PD parameter, TRIM investigations produced on average 7 findings. A significant number of findings are related to the long-run average. The shortcomings on this topic are typically linked to the calculation of default rates and to the definition of the period representative of the long-run average. A comparable number of findings still concerning PD are also related to risk differentiation. This was one of the areas in which the assessment teams performed extensive analyses challenging the PD models in place at the institutions. The shortcomings in this area are typically connected to a lack of consideration of relevant risk drivers or to the lack of an appropriate definition of the grades.

Regarding the LGD parameter, TRIM investigations produced on average 13 findings. The highest number of findings relate to the calculation of realised LGD. Shortcomings in this area typically involve one or more of the following potential issues: on the one hand, the use of an inappropriate discount rate (e.g., risk-free rate or contractual interest rate) and the treatment of multiple defaults (e.g., lack of an appropriate treatment to account for possible dependency among multiple defaults); on the other hand, specific aspects of the calculation (e.g. lack of an appropriate treatment of restructuring cases or insufficient consideration of indirect costs) observed during the intensive walk-throughs performed by the assessment teams during the on-site investigations. In addition to the calculation of realised LGD, a significant share of findings is related to the estimation of long-run

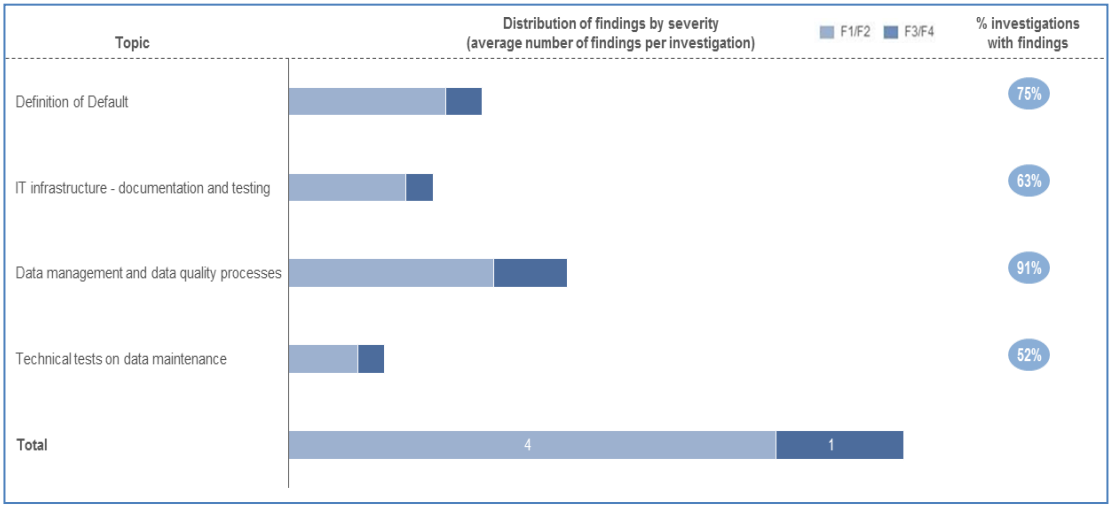
average LGD, in particular the treatment of incomplete work-outs, the downturn adjustment and the treatment of defaulted assets (i.e., models for expected loss best estimate - ELBE).

Finally, common to both PD and LGD, a significant number of findings relate to the frameworks for determining margins of conservatism and for the review of estimates.

Data quality

The TRIM exercise also includes the review of data management practices applied by the institutions to the specific credit risk models under review, as well as the review and assessment of the quality of PD and LGD historical data used for IRB modelling purposes. The review of these topics started in 2017 within the TRIM investigations on retail and SME models and will continue in the context of the low-default portfolio investigations. Where appropriate, findings related to data quality have been addressed in the context of the supervisory decision issued as a follow-up to each TRIM investigation. Through the horizontal analysis of shortcomings related to data quality, it was possible to identify areas characterised by non-compliance with the relevant regulatory framework, or by a divergence from the best practices highlighted in the ECB guide which caused data quality issues. These shortcomings are clustered along the areas of analysis in Figure 8, which shows their number and distribution.

Figure 8: Data quality review – examples of findings



Source: European Central Bank (2019), Second update on TRIM outcomes.

Data quality-related findings are present in all institutions investigated. More specifically, nearly all on-site investigations revealed issues relating to the data management and data quality processes in place, in many instances affecting several sub-topics such as: i) the data quality framework's governing principles and scope of application; ii) policies on data quality management and processes; iii) the allocation of roles, responsibilities and ownership in relation to the management of data quality; iv) the current metric approach for monitoring data quality; v) processes for data quality incident remediation and the reporting on data quality. The topic of data management and data quality processes presented the greatest share of findings with higher severity (F3/F4).

Shortcomings related to the IT infrastructure were identified in almost two-thirds of the on-site investigations; they are mainly connected to a lack of documentation of the IT infrastructure and data processes in place and to issues damaging the overall soundness, robustness and consistency of the IT set-up.

The on-site investigations also revealed a significant number of findings on the more technical data quality aspects, including the technical implementation of the Definition of Default (DoD) and technical tests on the data maintenance.

The findings on DoD were mainly related to the technical implementation of the DoD, but also included findings related to the regulatory compliance with DoD even though this aspect has not been a main focus of TRIM.

4.2. Data Quality and Data Governance

Since it was introduced in the previous paragraph, an exact definition of data quality should be provided and its difference from data governance should be outlined.

- Data Quality (DQ) is the degree to which data is accurate, complete, timely, and consistent with all requirements and business rules. Data quality is defined as the perception or assessment of fitness of data within a given context, meaning it is a measurement of data, thus the degree to which information consistently meets the expectations and requirements of the users/workers using it to perform their jobs. It is predominantly executed as an IT specialty and managed thru by those proficient in specialist data quality and data management tools;
- Data Governance (DG) is the exercise of authority, control, and shared decision making (e.g. planning, monitoring, and enforcement) over the management of data assets. Data governance refers to the policies and procedures geared towards the overall management of usability, availability, integrity and security of data. In other words, it is about a function owned by the business and executed by the business stewards in order to recognise and unlock the value of data to an enterprise and manage it as an enterprise asset.

Data quality only exists based on the value customers perceive with respect to meeting their needs. Data not required to support any business processes, or required to make decisions, or useful in trend-analysis is irrelevant. Even if the data is accurate and has inherent quality, it has no value to the enterprise. The more data can be shared across the organisation the more valuable it becomes, increasing the value of data within the enterprise, which is the primary goal for Data Governance. The moment that data is shared across business groups, it becomes an enterprise asset that must be governed in order to protect it and maximise its value to the organisation as well as enable the organisation to reduce costs in maintaining it. Data quality initiatives have a greater impact and return when they are mandated through the Data governance entity. Governance is inherently an integration challenge and for it to be successful it must be more than a collection of data quality initiatives. At its core, data governance encompasses three key areas: people, process and technology. In other words, a data governance framework assigns ownership and responsibility for data, defines the

processes for managing data, and leverages technologies that will help enable the aforementioned people and processes.

At the end of the day, data quality and data governance are not synonymous, but they are closely related. Quality needs to be a mandatory piece of a larger governance strategy, in order to allow an organisation to successfully manage and govern its most strategic assets, its data.

4.2.1. Data quality issues in the financial sector

As can be deduced by the fact of having been included in the TRIM review, in the financial services world data quality is of massive importance. All sectors in the financial markets have seen exponential increases in data volume through a variety of sources, a typical bank has over 500 million data elements per $1 billion in assets. The purpose of financial institutions is to leverage data in the quest for leaner organisations, better operational efficiency, and increased revenues. The quality of data not only impacts the success of these initiatives, but is also imperative to the firm's business agility, productivity and survival likelihood. In addition, for regulated firms in financial sectors, poor data quality can result in breaches, potential fines, and reputation loss. To be competitive and compliant, banks need quality data which is accessible and can be trusted.

Poor data quality leads to errors in decision making, which can be costly. Incorrectly marketed products, for instance, will see poor spread at best, and at worst can actually cause customer attrition. Accurate customer segmentation can also improve customer satisfaction, since risk profiling can be completed more accurately, and therefore customers can be proposed lower interest rates and better service offerings.

The accuracy of advanced analytics capabilities, which are being introduced in banks, such as machine learning, artificial intelligence and big data are heavily dependent on the quality of the raw material data.

The quality of data is also critical for compliance reasons. For anti-money laundering (AML) purposes, for example, banks need to be able to verify information, trace transactions and so on, which requires accurate and accessible information. The accuracy of risk calculations, as regulated by the Basel Committee on Banking Supervision's standard number 239 (BCBS 239) which contains principles of a sound data governance framework and will be discussed in the next paragraph, must also be verifiable and impacts the amount of capital a bank must hold in reserve. Better quality risk data frees up capital to give better returns to shareholders; for instance, if for regulatory reporting you have to use defaults where data fields are empty or invalid, then you will default to worst, potentially overstating capital needs and risks. And, of course, the Protection of Personal Information (PoPI) Act, and similar regulations around the world require that customer's data be of adequate quality so as to ensure that decisions made based on that data are not prejudicial.

In addition, there is a hidden operational cost to poor quality data. For example, if the contact details a bank has for a customer are incorrect and the customer defaults, the bank will be unable to contact him, which will require significant additional expense to collect on defaulted payments.

Data needs to be captured correctly from the outset – the well-known 1-10-100 rule applies here. If it costs a bank R1 to capture the information, it will cost it R10 to correct it and R100 in additional costs to resolve issues caused by incorrect information.

With the objective of avoiding the problems above, the ECB and BCBS pay close attention to supervised entities' data quality, risk data aggregation and risk reporting capabilities, which are considered essential preconditions for proper risk governance and sound risk-based decision-making and require advanced IT infrastructure. The importance of these elements increased since the 2008 financial crisis, which demonstrated that an institution's ability to manage risk-related data has a significant impact on its overall risk profile and the sustainability of its business model, especially when such entities face economic, financial, competitive and regulatory difficulties. In this context the BCBS and the ECB started a strengthening program of the prudential supervision framework, including a number of initiatives, mainly referred to Pillar 1 and 2, aimed at addressing the shortcomings revealed by the crisis itself. Therefore, even before the start of the TRIM, the topic of data quality and data governance had already been addressed at the global level; among the numerous actions, it is interesting to further explore the Basel Committee on Banking Supervision's standard number 239, mentioned before.

4.3. BCBS 239 - Risk data aggregation and risk reporting principles

The global financial crisis showed that banks' information technology (IT) and data architectures were inadequate to support the broad management of financial risks. Due to weak data aggregation capabilities and risk reporting practices, several banks lacked the ability to aggregate risk exposures and identify concentrations quickly and accurately at the bank group level, across business lines and between legal entities, leading to heavy consequences for the individual banks and also for the entire financial system. A robust data framework certainly helps banks and supervisors in a dual way; on one hand it allows to anticipate problems before their occurrence, on the other hand it provides alternative options to restore financial strength and viability in case of difficult situations.

In this context the Basel Committee issued in 2013 the BCBS239 - Risk Data Aggregation and Risk Reporting Principles, that require the intermediaries to adopt a comprehensive and formalised framework for the risk data and reporting governance, with the purpose of both improving the quality of risk management processes and empowering the interaction with Supervisors. The term "risk data aggregation" means defining, gathering and processing risk data according to the bank's risk reporting requirements to enable the bank to measure its performance against its risk tolerance/appetite[47]. This

[47] "Risk appetite is the level and type of risk a firm is able and willing to assume in its exposures and business activities, given its business objectives and obligations to stakeholders" as defined by the Senior Supervisors Group report, Observations on Developments in Risk Appetite Frameworks and IT Infrastructure (2010).

includes sorting, merging or breaking down sets of data. Those principles are expected to support a bank's efforts to:

- Enhance the infrastructure for reporting key information, in particular, those used to manage risks;
- Improve the decision-making process through the banking organisation;
- Enhance the management of information across legal entities, facilitating the assessment of risk exposures at the global consolidated level;
- Reduce the probability and severity of losses resulting from risk management weaknesses;
- Increase the speed at which information is available and, consequently, decisions can be made;
- Improve the organisation's quality of strategic planning and the ability to control risks related to new products and services.

The effective implementation of the principles generates a cost for the banks, but the benefits are expected to be higher than the incurred costs because stronger risk management capabilities increase the value of a bank.

Initially, these principles were addressed to the global systemically important banks (G-SIBs), both at consolidated group level and at single legal entity level. G-SIBs designated in 2011 or 2012 had to meet the principles by January 2016, while the available time frame for the additional G-SIBs and for Domestic systemically important banks (D-SIBs) is within three years from formal designation. The principles and the related supervisory expectations apply to a bank's risk management data, meant as fundamental data for a bank to manage the risks it faces, and to all key internal risk management models, among which Pillar 1 regulatory capital models (e.g., IRB approach). The principles refer to the following four topics, strongly linked to one another.

Overarching governance and infrastructure

A bank should possess a strong governance framework, risk data architecture and IT infrastructure.

1. Principle 1: Governance – a bank's risk data aggregation capabilities and risk reporting practices should be subject to strong governance arrangements consistent with other principles and guidance established by the Basel Committee;
2. Principle 2: Data architecture and IT infrastructure – a bank should design, build and maintain data architecture and IT infrastructure which fully supports its risk data aggregation capabilities and risk reporting practices not only in normal times but also during times of stress or crisis, while still meeting the other principles.

Risk data aggregation capabilities

In order to guarantee that risk management reports reflect the risks in a reliable way, banks should develop and maintain strong risk data aggregation.

3. Principle 3: Accuracy and integrity – a bank should be able to generate accurate and reliable risk data to meet normal and stress/crisis reporting accuracy requirements. Data should be aggregated on a largely automated basis so as to minimise the probability of errors;
4. Principle 4: Completeness – a bank should be able to capture and aggregate all material risk data across the banking group. Data should be available by business line, legal entity, asset type, industry, region and other groupings, as relevant for the risk in question, that permit identifying and reporting risk exposures, concentrations and emerging risks;
5. Principle 5: Timeliness – a bank should be able to generate aggregate and up-to-date risk data in a timely manner while also meeting the principles relating to accuracy and integrity, completeness and adaptability. The precise timing will depend upon the nature and potential volatility of the risk being measured as well as its criticality to the overall risk profile of the bank. The precise timing will also depend on the bank-specific frequency requirements for risk management reporting, under both normal and stress/crisis situations, set based on the characteristics and overall risk profile of the bank;
6. Principle 6: Adaptability – a bank should be able to generate aggregate risk data to meet a broad range of on-demand, ad hoc risk management reporting requests, including requests during stress/crisis situations, requests due to changing internal needs and requests to meet supervisory queries.

Risk reporting practices

Accurate, complete and timely data alone do not guarantee effective decisions about risks by the board and senior management. Risk reports based on risk data should be accurate, clear and complete; they should contain the correct content and be presented to the suitable decision-makers in a time that allows for an appropriate response.

7. Principle 7: Accuracy - risk management reports should accurately and precisely convey aggregated risk data and reflect risk in an exact manner. Reports should be reconciled and validated;
8. Principle 8: Comprehensiveness - risk management reports should cover all material risk areas within the organisation. The depth and scope of these reports should be consistent with the size and complexity of the bank's operations and risk profile, as well as the requirements of the recipients;
9. Principle 9: Clarity and usefulness - risk management reports should communicate information in a clear and concise manner. Reports should be easy to understand yet comprehensive enough to facilitate informed decision-making. Reports should include meaningful information tailored to the needs of the recipients;
10. Principle 10: Frequency – the board and senior management (or other recipients as appropriate) should set the frequency of risk management report production and distribution. Frequency requirements should reflect the needs of the recipients, the nature of the risk reported, and the speed, at which the risk can change, as well as the importance of reports in contributing to sound risk management and effective and efficient decision-making across the bank. The frequency of reports should be increased during times of stress/crisis;

11. Principle 11: Distribution - risk management reports should be distributed to the relevant parties while ensuring confidentiality is maintained.

Supervisory review, tools and cooperation

Supervisors must monitor the implementation of the principles by banks. Moreover, they should review compliance with the principles across banks to check whether further improvements are necessary.

12. Principle 12: Review - supervisors should periodically review and evaluate a bank's compliance with the eleven Principles above;
13. Principle 13: Remedial actions and supervisory measures - supervisors should have and use the appropriate tools and resources to require effective and timely remedial action by a bank to address deficiencies in its risk data aggregation capabilities and risk reporting practices. Supervisors should have the ability to use a range of tools, including Pillar 2;
14. Principle 14: Home/host cooperation - supervisors should cooperate with relevant supervisors in other jurisdictions regarding the supervision and review of the Principles, and the implementation of any remedial action if necessary.

4.4. Elements characterising the management of IRB data

Coming back to the Targeted Review of Internal models, in order to evaluate the level of adequacy of data quality and data governance within the institutions in scope, the ECB considered the management of IRB data from three different perspectives:

1. IT systems: infrastructure and implementation testing;
2. Policies, roles and responsibilities in data processing and data quality management;
3. Components of the data quality management framework.

4.4.1. IT systems: infrastructure and implementation testing

Robust IT infrastructures are fundamental in supporting a bank's rating systems. In order to comply with the documentation requirements for the rating systems established under Article 144(1)(e) and Article 175(1) of the CRR, banks should document in a clear way, by maintaining an updated register, all current and past versions of the following elements of a rating system:

- The flow of the model's data, which include internal, external and pooled data (from data entry[48] to reporting and for both historical data and current exposure data), while determining the workflows and procedures related to extraction, collection, storage and transformations of data;

[48] This refers to the first entry or registration of data in the institutions' systems and applications or in the core systems of the institutions where the raw data first originated.

- The sources of data and the map of IT systems and databases that take part in the calculation systems used for the IRB approach;
- The functional specification of IT systems and databases, indicating their size, date of construction and data dictionaries, describing the content of the fields and of the valid data values which could be inserted in them;
- The technical specification of IT systems and databases, defining the type of database, tables, database management system, database architecture and data models;
- The audit trail for critical IT systems and databases.

To ensure the integrity and robustness of IT systems[49], and in particular that in terms of IT the implementation of the models is successful and error-free, institutions should have in place a process for testing the IRB systems, which should be clearly defined and documented within the organisation policies. The testing procedure should be implemented after the first application of the IRB models and on an ongoing basis, considering all potential triggering events, which include software releases or material IT-related changes, regulatory changes, model methodology changes and the extension of the range of application of a rating system.

Examples of IT implementation tests that must be considered are:

- Unit / component / module tests;
- Integration tests (of units and between systems);
- System tests (these include functionality, performance – both in normal and stress scenarios – and security and portability tests);
- User acceptance testing (functional testing);
- Regression testing.

The unit responsible for the implementation of the above tests should be identified and a standardised format for the documentation of their results should be developed.

4.4.2. Policies, roles and responsibilities in data processing and data quality management

To comply with the requirement to collect and store all relevant data established under Article 144(1)(d) of the CRR, institutions should define policies and rules on data management at group level for both data processing and data quality management.

In the field of data processing, particularly with respect to manual interventions and data transfers, it is important to take into account the following principles:

- To ensure that all data transformations are traceable and controlled, general guidelines and rules should be clearly formalised with regard to manual interventions within the data processing;

[49] See Article 144(1) of the CRR.

- To ensure timeliness and accountability, all data transfers should be formally agreed upon by data providers and data users (for both outsourced and in-house processes).

To ensure the integrity of the data processes, the policies and rules on data management should clearly define the relevant data governance arrangements and specify the different roles and responsibilities assigned to data management. These include data quality roles and responsibilities for both business owners and IT functions and data and systems ownership throughout the entire credit risk modelling life cycle (including also all IT systems used). The policies should consider the following principles.

- The responsibilities of business owners include:
  - Ensuring data are correctly entered, kept up to date and aligned with the institution's data definitions;
  - Ensuring that data aggregation capabilities and reporting practices are consistent with the institution's policies.
- IT functions are responsible for supporting the operation of the systems for data collection, processing, transformation and storage during the entire life cycle of the data;
- Different business owners and IT systems owners may be appointed throughout the data life cycle. However, each data source, IT system and process step should have an assigned business owner and/or IT systems owner that can be formally identified.

Institutions must have in place a process for examining data inputs into the model, which has to include an assessment of the accuracy, completeness and appropriateness of the data[50]. To comply with this requirement and to ensure the quality of the data used for credit risk measurement and management processes, institutions should establish and implement an effective data quality management framework that is formalised in a set of policies and procedures. This framework should be applicable to all data used in IRB-related processes, i.e. internal data, external data and pooled data. In addition, it should ensure that reliable risk information is available to enable an institution's risk profile to be assessed accurately and drive sound decision-making within the institution and by external stakeholders, including competent authorities.

4.4.3. Components of the data quality management framework

According to the ECB view, the data quality management framework is effective only if it includes all the following components.

Governance principles for the data quality management framework

The data quality management framework:

- should be approved by the institution's management body or a designated committee and senior management as part of their responsibilities;
- should be distributed throughout the organisation to the relevant staff;

[50] See Article 174(b) of the CRR.

- should be regularly assessed in order to verify its adequacy, and be updated and improved whenever necessary;
- should be subject to regular review by the internal audit function or another comparable independent auditing unit.

The roles of the different units, internal bodies and staff involved in the management of data quality should be defined in a way that ensures that data quality management activities are independent of data processing activities. In line with the ECB opinion, it is good practice for institutions to have a dedicated independent unit, whose size should be proportionate to the complexity of its business and organisational structure, with an overall view of and responsibility for the management of data quality.

Scope of the data quality management framework

The data quality management framework:

- should cover all relevant data quality dimensions: completeness, accuracy, consistency, timeliness, uniqueness, validity, availability and traceability;
- should cover the whole data life cycle, from data entry to reporting, and encompass both historical data and current application databases.

In case institutions use data provided by third parties, they should ensure that the third party has data quality processes in place to ensure the accuracy, completeness and appropriateness of the data provided.

Data quality standards in the data quality management framework

To comply with the requirement described in Article 174(b) of the CRR, also mentioned before, of conducting an assessment of the accuracy, completeness and appropriateness of data inputs into the model, institutions should establish data quality standards that set the objectives and overall scope of the data quality management process. These standards should, therefore, be defined for the following data quality dimensions[51] for all data inputs into the model and at each stage of the data life cycle.

- Completeness: values are present in any attributes that require them;
- Accuracy: data are substantively error-free;
- Consistency: a given set of data can be matched across the institution's different data sources;
- Timeliness: data values are up to date;
- Uniqueness: aggregate data are free from any duplication arising from filters or other transformations of source data;
- Validity: data are founded on an adequate and rigorous classification system that ensures their acceptance;

[51] It is the ECB's view that the CRR reference to appropriateness of data inputs comprises the following additional data quality dimensions: consistency, timeliness, uniqueness, validity, availability/accessibility and traceability.

- Availability/Accessibility: data are made available to the relevant stakeholders;
- Traceability: the history, processing and location of the data under consideration can be easily traced.

Data quality controls

Data quality should be measured in an integrated and systematic way, formalising the measurement system and the frequency of its application.

Indicators, with their corresponding tolerance levels and thresholds, should be defined in order to check compliance with the standards established and should be combined with visual systems (e.g., red/amber/green traffic-light system) and dashboards for monitoring and reporting purposes.

Indicators alone are not enough; they should be supported by effective and sufficient data quality checks and controls throughout the entire data life cycle, from data entry to reporting, and for both historical data and current application data. Data quality checks and controls should include reconciliation across and within systems, including between accounting and IRB data. Thus, an effective control framework should be in place to ensure that sound controls and related procedures are implemented, especially for manual processes.

Remediation of data quality issues

A process for the identification and remediation of data quality deficiencies should be set with the purpose of constantly improving data quality and promoting compliance with the data quality standards.

Data quality assessments should be carried out independently and recommendations should be issued with an indication of their priority, based on the materiality of the incidents identified. All the data quality incidents detected should be recorded and monitored; for each of them an owner responsible for their resolution should be appointed and an action plan for their handling should be formulated on the basis of the priority assigned. Remediation timelines should depend on the severity and impact of the incident and the implementation timelines required to resolve it. Data quality incidents should be resolved at source level[52] or, if this is not possible, mitigated by taking a prudent approach.

Data quality reporting

Article 189(2)(c) of the CRR requires the institution's senior management to ensure, on an ongoing basis, that the ratings systems are working properly. To achieve this goal, the ECB believes that a formal reporting process on the quality of risk data should be in place with the objective of improving the quality of data and permitting an assessment of the potential impact of data quality in own fund

[52] From the source system in which the incidents are present down to the IRB datasets or systems.

requirements calculations. In general, this reporting should be presented in a standardised format with clear and concise content, which in turn should include the following topics:

- Comprehensive overview of the performance of the model in terms of data quality, including external data and pooled data, if any, at all stages of the IRB life cycle, from data entry to reporting, for both historical data and current exposure data;
- Findings and, where applicable, recommendations to deal with detected weaknesses or shortfalls;
- Sufficient and appropriate evidence that the recommendations have been adequately addressed and properly implemented (e.g., by means of a status report).

To comply with the requirement set by Article 189(1) of the CRR, which states that the management body or a designated committee and senior management must possess a general understanding of the rating systems of the institution and a detailed comprehension of its associated management reports, reports on the quality of risk data should be submitted to these parties. In addition, the ECB considers it good practice for the institutions to submit these reports to all other relevant staff, including modellers, internal validation, internal audit, data quality managers, data owners and other business units involved. Data quality reports should be produced and submitted to senior management more frequently than annually; in this way senior management can ensure, on an ongoing basis, that the rating systems are operating properly, in accordance with Article 189(2)(c) of the CRR.

CHAPTER 5 - TRIM DATA QUALITY CREDIT RISK

5.1. BCE on-site inspections for TRIM: findings and obligations

After having explored the Targeted Review of Internal Models from the perspective of the ECB, in terms of expectations and organisation of the project itself, it is now interesting to investigate how the banking group in question addressed the issues detected by the supervisory entities during the performing of the TRIM.

Starting from 2016, this banking group is included, together with other 64 Significant Supervised Entities at European level, in the ECB project Targeted Review of Internal Models (TRIM). As said before, this project, focused on credit, market and counterparty credit risk, aims to reduce the excessive variability in the outcomes obtained from the use of Pillar I internal models by banks, and to restore the credibility, adequacy and appropriateness of those models. Although the TRIM covers various field, following the same approach adopted before, the only focus will be on the credit risk area and more specifically on the data quality framework.

The ECB communicated the start of the TRIM to the bank in question on January 20, 2016. In order to understand how this banking group reacted to the shortcomings discovered during the investigation, with the objective of restoring compliance with the ECB and BCBS guidelines, it is necessary to separately analyse the inspections performed for the different credit risk portfolios and the related findings identified by the Joint Supervisory Team.

Credit risk high-default portfolios

During the phase dedicated to the review of the models used to assess the credit risk for high-default portfolios, the inspections involved specifically Retail and SME Corporate portfolios.

Retail

The on-site activities of the assessment team took place from April 18, 2017 until July 14, 2017. Among the gaps identified, Finding #5 was related to the lack of an effective data quality framework. According to the JST, “there was no evidence of the controls, covering all relevant data quality dimensions of PD, LGD and CCF data, periodically executed; furthermore, a formal procedure to remediate data quality issues was not in place. There were no formal and documented standards regarding the quality of IRB data nor an IRB data quality dedicated report. Moreover, there was no clear separation of functions between the resources in charge of data processing and those in charge of data quality activities”.

The mentioned finding gave rise to an obligation, named Obligation #4, notified in August 2018 and to be satisfied by the supervised entity within 12 months after the notification of the decision, thus in August 2019. Obligation #4 stated that “the bank should implement an effective data quality framework, providing evidence that it covers all relevant data quality dimensions of PD, LGD, and CCF data used, specifically accuracy and traceability, and providing details regarding the set of

controls and its frequency. The banking group should ensure that data quality management processes with the purpose of identifying, mitigating, tracking and remediating data quality issues are in place; those processes should be subject to independent periodical review regarding the correct application and their effectiveness. The data quality framework should be integrated with a system of data quality indicators and corresponding thresholds regarding the quality of IRB data. The entity should set a regular reporting on these indicators, in order to provide a holistic view on the quality of data along the IRB data chain. Finally, the institution should ensure an adequate degree of independence between the data collection and the data quality management process, and a proper allocation of ownership, roles and responsibilities along the IRB data process chain".

SME Corporate

The on-site activities of the assessment team took place from February 5, 2018 until April 13, 2018. Among the shortages identified, the following are related to the data quality matter.

- Finding #10 referred to incomplete documentation related to the IRB IT infrastructure. According to the JST, "the available documentation describing the IRB IT infrastructure did not always allow third parties to clearly understand the existing framework; for instance, it was not clear what kind of flow was provided by each system. The description of roles and responsibilities for IRB infrastructure was not updated in the available documents and was no more coherent with the bank's current organisational chart. Furthermore, ownerships for each system / application of the data cycle of the data for PD/LGD models were not allocated";
- Finding #11 was related to the lack of an effective data quality framework. According to the JST, "there was no evidence of the controls, covering all relevant data quality dimensions of PD, LGD and CCF data, periodically executed; furthermore, a formal procedure to remediate data quality issues was not in place. There were no formal and documented standards regarding the quality of IRB data nor an IRB data quality dedicated report. Moreover, there was no clear separation of functions between the resources in charge of data processing and those in charge of data quality activities";
- Finding #13 concerned the scope of the mandatory tests for information about the metrics PD and LGD. According to the JST, "the PD / LGD mandatory tests were not performed through the whole life cycle of the data (all systems / databases related to the IT workflow for PD and LGD), which was considered the expected scope".

The findings above gave rise to an obligation, named Obligation #7, notified in September 2019 and to be satisfied by the supervised entity within 12 months after the notification of the decision, thus in September 2020. Obligation #7 stated that "the bank should implement an effective data quality framework, providing evidence that it covers all relevant data quality dimensions of PD, LGD, and CCF data used, specifically accuracy and traceability, and providing details regarding the set of controls and its frequency. The banking group should ensure that data quality management processes with the purpose of identifying, mitigating, tracking and remediating data quality issues are in place; those processes should be subject to independent periodical review regarding the correct application and their effectiveness. The data quality framework should be integrated with a system of data quality

indicators and corresponding thresholds regarding the quality of IRB data. The entity should set a regular reporting on these indicators, in order to provide a holistic view on the quality of data along the IRB data chain. The institution should ensure an adequate degree of independence between the data collection and the data quality management process, and a proper allocation of ownership, roles and responsibilities along the IRB data process chain. Finally, the documentation describing the IRB IT infrastructure (data sources and related process) should be improved to allow third parties to gain full understanding of the current infrastructure".

Credit risk low-default portfolios

During the phase dedicated to the review of the models used to assess the credit risk for low-default portfolios, the inspections involved specifically Large Corporate and Institutions portfolios.

Large Corporate

The on-site activities of the assessment team took place from January 15, 2019 until March 31, 2019. Among the weaknesses identified, Finding #5 was associated to data quality framework flaws. According to the JST, "there was no evidence of the set of controls periodically executed in all relevant stages of the data lifecycle. A formal procedure aimed at identifying, mitigating, tracking and remediating data quality issues was not in place. Finally, despite the identification of data quality indicators, thresholds were not formally defined, and an IRB data quality dedicated report was not produced".

So far, no obligation has been formalised by the ECB.

Institutions

The on-site activities of the assessment team took place from April 8, 2019 until July 25, 2019. The possible shortcomings identified by the JST have not yet been communicated to the bank.

5.2. Introduction to the TRIM Project – Data Quality Credit Risk

Within the ECB initiative Targeted Review of Internal Model (TRIM) the banking group launched in September 2018 a dedicated project, called TRIM Data Quality Credit Risk, focused on Data Governance and Data Quality topics and aimed at addressing the Obligation #4 formalised by the ECB on August 31, 2018 for TRIM Retail and to be satisfied within August 31, 2019, and other indications arisen from the Exit Meeting of TRIM SME Corporate. Therefore, the project adopted a cross-segment approach on the PD and LGD parameters, going beyond the specific perimeter of the Retail segment subject of the Obligation #4, in order to ensure a Data Governance framework on the relevant and mandatory data used for the model estimation. The TRIM DQ project allows to accelerate the path towards the structural recover of the knowledge; it may be considered as the trigger of a virtuous route for the extension and application of the Data Governance framework (tools, processes and operating practices) and it will provide the elements for the definition of standards and the evaluation of their applicability and sustainability.

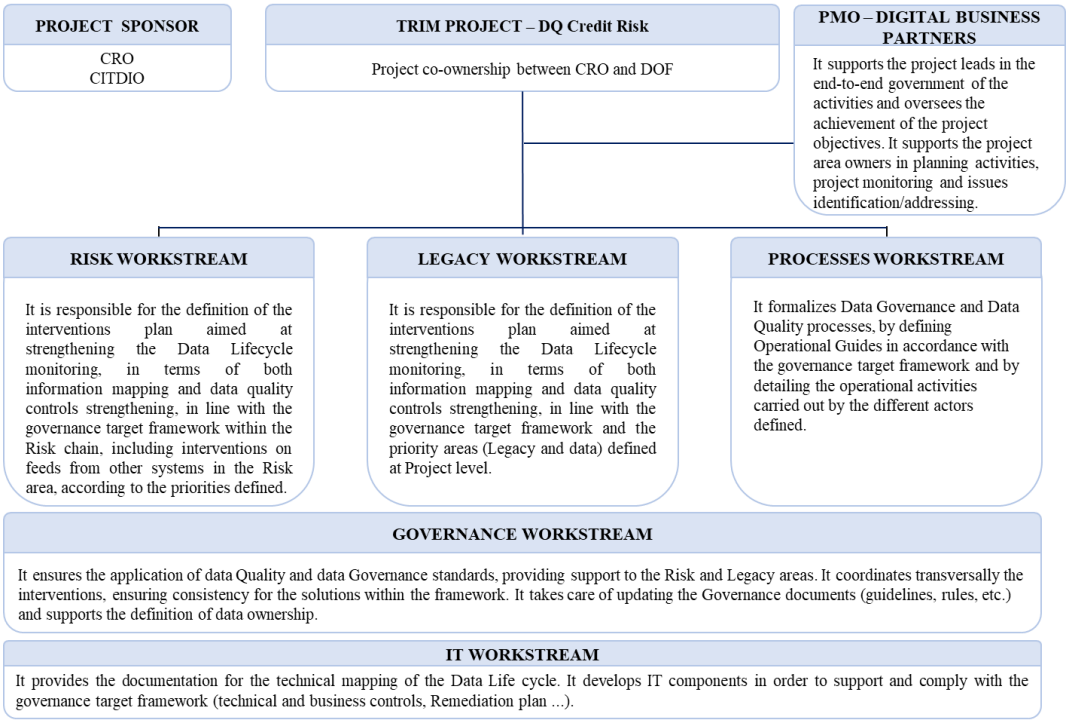
5.2.1. Corporate functions involved and organisational chart

The project is led jointly by the Chief Risk Officer (CRO) and the Chief IT, Digital and Innovation Officer (CITDIO), which both embody the Project Sponsor[53], with the involvement of all the corporate functions engaged in the lifecycle of the data used for the estimation of PD and LGD models to strengthen the Data Governance framework.

The CRO Governance Area is responsible for governing the macro-process of definition, approval, control and implementation of the Group's Risk Appetite Framework with the support of the other corporate functions involved; moreover, it is in charge of assisting the Bodies in defining guidelines and policies on risk management and coordinating their implementation by the relevant Group business units. The CITDIO Governance Area is responsible for supporting, in line with the Business Owners' requirements, the definition and development of innovation initiatives, technologies and solutions to be applied within the time frame of the Business Plan; furthermore, it is accountable for coordinating the definition and implementation of the data governance system to ensure a high level of quality and meet regulatory and business requirements.

Specifically, the functions taking part to the project are PMO – Digital Business Partners, Risk, Legacy, Processes, Governance and IT. The following organisational chart shows their structure and describes the tasks they carry out in order to contribute to the success of the project.

Figure 9: TRIM Data Quality Credit Risk organisational chart



Source: Accenture

[53] The Project Sponsor is composed of the corporate functions which, having the highest interest in the project, are representatives of the project itself to the Executive Board and are responsible for its success or failure.

Aiming at best managing the inspections and coordinating the analysis activities and answers to be progressively provided to the JST, a Task Force (DQ FQ) has been established with the task of addressing the various requests, at the same time guaranteeing connection and coherence with the project TRIM Data Quality Credit Risk's working plan. Specifically, the Task Force is coordinated by the CRO and DOF workstreams' leaders and is composed of Risk, Legacy, Processes, IT and Coordination (DBP) workstreams' leaders. The Task Force takes the format of a mandatory round table taking place three times a week, whose participants are the DQ TF, TRIM Steering Committee and Internal Validation; its objective is to clarify the status of ongoing activities and coordinate the answers to the JST. The Data Quality Task Force's main goals are the following:

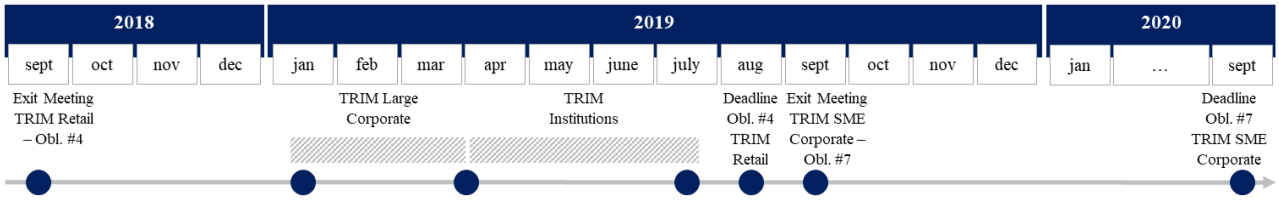
- Interaction with the TRIM Steering Committee: interacting with TRIM Steering Committee to support Users to respond correctly to requests referring to DQ process;
- Coherence of evidences: verifying – in relation to requests involving several units – the coherence of the contributions received;
- Pre-analysis of the requests: performing a pre-analysis of JST requests related to data quality topics;
- Food for thought pro Master Plan: factorising - as far as possible – any possible food for thought came out during the TRIM within the Master Plan pro Obligation #4;
- Coherence with the project activities: ensuring coherence with the project activities pro Obligation #4;
- Addressing requests: conveying requests to the most appropriate structure in order to answer to Supervisor requests.

5.2.2. Regulatory context and project goals

As said before, the shortcomings identified during the on-site inspections for the Retail portfolio, related in particular to the documentation, IT infrastructure and Data Quality framework, have been formalised by the ECB on August 31, 2018 through the Decision Letter and its connected Obligation, denominated Obligation #4, which describes in detail the shortfalls that the bank must address and requires the implementation of an action plan aimed at the resolution of the obligation itself within12 months after the notification of the decision, thus within August 31, 2019.

The project started in September 2018 pointing to address the Obligation #4, together with other indications arisen from the Exit Meeting of TRIM SME Corporate. Similarly to what happened for the Retail portfolio, the shortcomings identified during the on-site inspections for the SME Corporate portfolio have been formalised by the ECB on September 30, 2019 through the Decision Letter and its connected Obligation, denominated Obligation #7. The Obligation 7 will have to be resolved within12 months after the notification of the decision, thus within September 30, 2020; this means that the project will go on at least until that date. To facilitate the understanding, Figure 10 shows the timeline of the on-site inspections and the Obligations, limited to the period from August 2018 until September 2020.

Figure 10: Timeline of on-site inspections and Obligations



Source: Accenture

Although the project started in September 2018, where possible, project activities have been modified with the purpose of meeting in a more efficient manner the expectations of the JST during the two on-site inspections for Large Corporate and Institutions portfolios planned in the first semester of 2019, so as to organise deliverables' tranches as much coherent as possible with the topics under assessment. Precisely, the inspection related to the Large Corporate portfolio revealed 57 additional requests (issues) concerning data quality. Thus, attempts have been made to include in the project plan the evidences arisen during that inspection, trying to limit as much as possible potential relapsed on the Obligation #4 plan.

The project is focused on the whole lifecycle of data involved in the Laboratory for PD and LGD/EAD models estimation, with the following goals:

- Implementation of a data quality framework subject to independent revision and definition/application of an organisational process related to IRB area;
- Implementation of a set of data quality controls covering all data quality dimensions on the whole data lifecycle and design of reporting including synthetic data quality indicators on IRB area.

5.2.3. Project assumptions, scope and deliverables

The project aims at enforcing the Data Governance framework along the entire data flow from the source systems to the Risk Laboratories in terms of both data quality controls and documentation of data lifecycle, under a number of assumptions and within a specific scope of intervention. The assumptions underlying the execution of the project are the following:

- Interventions focused on PD and LGD/EAD Laboratory environment;
- Tracing back to the first level of feeding systems (i.e., Legacy) in terms of documentation and data quality controls.

The scope of project activities is organised as follows:

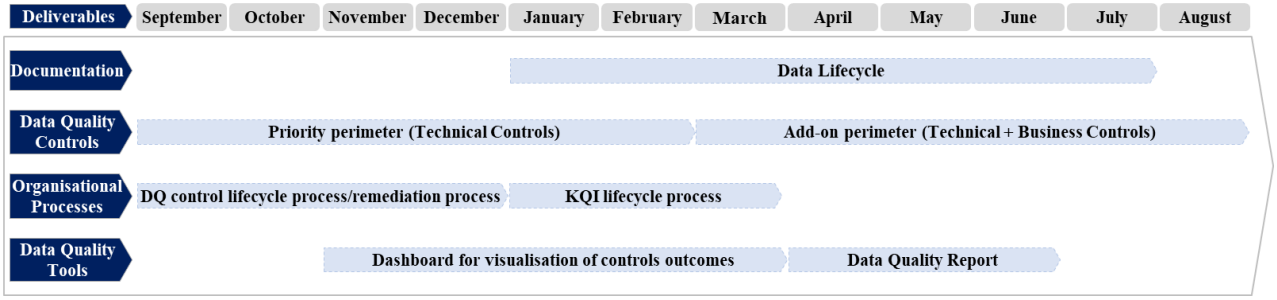
- Priority perimeter includes primary metrics for model estimation;
- Add-on perimeter includes further relevant information for model estimation.

Several and progressive deliverables have been identified in order to enhance the Data Governance framework, effectively addressing the Obligation #4.

- Data Lifecycle: technical/functional documentation describing the tabular data lineage and the treatments applied along the feeding process of the estimation laboratories of PD and LGD/EAD models;
- Data Quality Controls: design, implementation and collection into the data/controls dictionary of:
  - Technical controls: checks performed on entire input flow/dataset and aimed at verifying technical characteristics of all the contained data (i.e., format, duplicate key, …);
  - Business controls: checks performed on specific business relevant data. This kind of control requires the knowledge of data functional meaning and its implementation is subject to a business requirement;
  - Controls outcomes visualisation through data quality tool;
- Organisational processes:
  - Definition and application of organisational processes related to data quality framework (e.g., "data quality control lifecycle process", "remediation/escalation process", "key quality indicator lifecycle process");
  - Planning and implementation of dedicated interventions aimed at solving data quality issues (remediation);
- Data Quality Tools:
  - Implementation of a dashboard for the visualisation of controls outcomes;
  - Creation of an IRB data quality dedicated report for monitoring data quality indicators and corresponding thresholds.

Consistent with the priorities of the different deliverables, the Master Plan was drafted. The Master Plan is a document which defines in broad terms the sequence of achievement of the main project objectives over time.

Figure 11: Project Master Plan



Source: Accenture

As figure 11 shows, the activity targeted to produce documentation describing the whole lifecycle of data used for PD, LGD and CCF model estimation took place concurrently with the on-site inspections for low-default portfolio, with the objective of providing the requested documents to the assessment team. The implementation of the set of data quality controls was organised in two phases; during the first step only technical controls were implemented on the metrics included in the priority perimeter, the second stage, instead, involved the implementation of both technical and business controls on the metrics comprised in the add-on perimeter. Also the definition of guides of

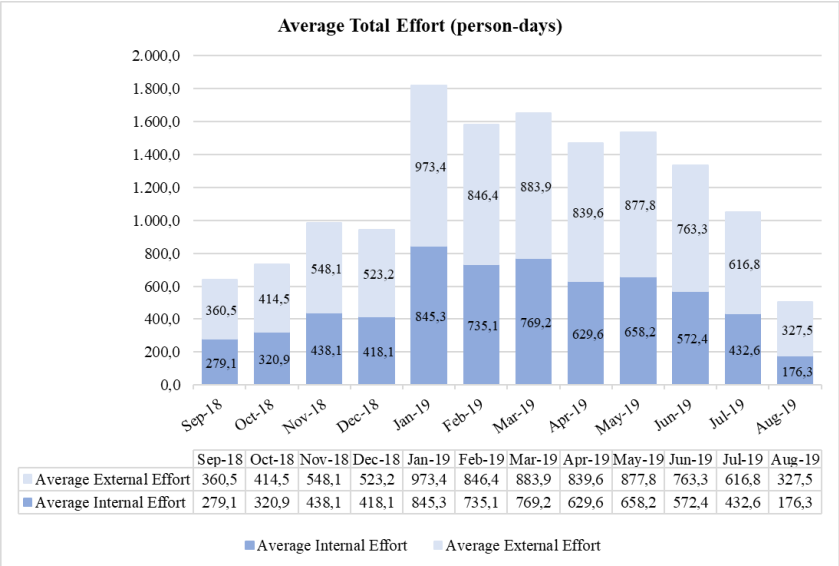
organisational processes related to the data quality framework and the introduction of data quality tools were distributed in two successive periods.

5.2.4. Estimation of the project cost

The estimation of the TRIM Data Quality Credit Risk's cost limited to the period from September 2018 until August 2019, spent to address Obligation #4, was defined following a retrospective approach. The starting point was the estimation of the total effort used to provide each deliverable; this estimation was assumed based on the type of activity performed to produce the deliverables and their duration. Then, the total effort was decomposed to assign the effort to the detailed tasks that together constitute a given macro-activity and to the working groups involved. During the estimating exercise four working groups, which encompass the whole workstreams described in the project organisational chart, were considered. Each working group include a different number of resources internal and external (consultants) to the bank, with the following composition:

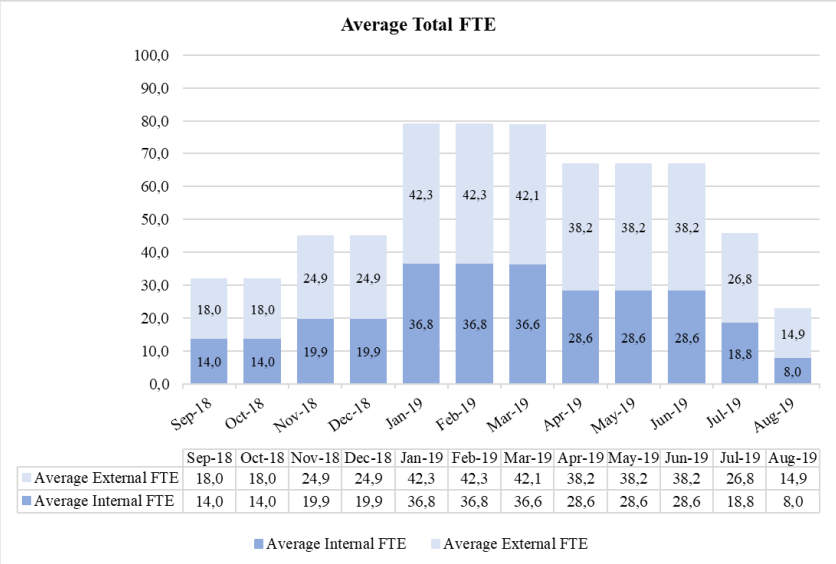
- Risk Workstream: 60% of internal resources and 40% of external resources;
- IT Infrastructure (including IT Infrastructure and Legacy Workstream): 20% of internal resources and 80% of external resources;
- Governance Workstream (including Governance and Processes Workstream): 70% of internal resources and 30% of external resources;
- PMO: 70% of internal resources and 30% of external resources.

By distributing the total effort, expressed in person-days, over the 12 months used to address Obligation #4, the following chart is obtained.



	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19
Average External Effort	360,5	414,5	548,1	523,2	973,4	846,4	883,9	839,6	877,8	763,3	616,8	327,5
Average Internal Effort	279,1	320,9	438,1	418,1	845,3	735,1	769,2	629,6	658,2	572,4	432,6	176,3

The information about the total effort allows to compute the estimation of the number of FTE (Full Time Equivalent) employed during the project. The FTE is mainly used to indicate the effort provided or planned to perform an activity or a project in terms of full-time resources. The FTE equals an employed person working full-time (8 hours per day); it is a measure to quantify the resources necessary to carry out a given activity. The following chart shows the number of FTE involved in the project tasks during the 12 months under consideration.

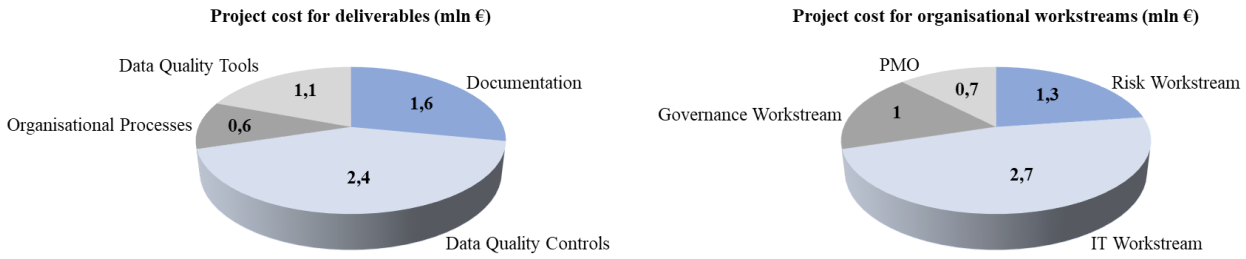


	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19
Average External FTE	18,0	18,0	24,9	24,9	42,3	42,3	42,1	38,2	38,2	38,2	26,8	14,9
Average Internal FTE	14,0	14,0	19,9	19,9	36,8	36,8	36,6	28,6	28,6	28,6	18,8	8,0

Coming back to the comprehensive view, for each deliverable the overall effort, employed by each group, was made explicit. In order to obtain the estimation in monetary terms, the effort was multiplied by a daily rate of 400 €/person-days; this rate represents an average of the rate actually related to internal (cheaper) and external (more expensive) resources. The total project cost was thus estimated in 5.7 mln €.

Deliverables	Organisational Workstreams	Effort (person-days)	Total Effort (person-days)	Average Rate (€/person-days)	Cost (€)
Documentation	Risk Workstream	1.500	4.000	400	1.600.000
	IT Workstream	1.500			
	Governance Workstream	500			
	PMO	500			
Data Quality Controls	Risk Workstream	1.000	6.000	400	2.400.000
	IT Workstream	4.000			
	Governance Workstream	500			
	PMO	500			
Organisational Processes	Risk Workstream	500	1.500	400	600.000
	IT Workstream	0			
	Governance Workstream	750			
	PMO	250			
Data Quality Tools	Risk Workstream	250	2.750	400	1.100.000
	IT Workstream	1.250			
	Governance Workstream	750			
	PMO	500			
Grandtotal			14.250		5.700.000

The following figures exhibits respectively the total cost divided for each deliverable and for each organisational workstream.

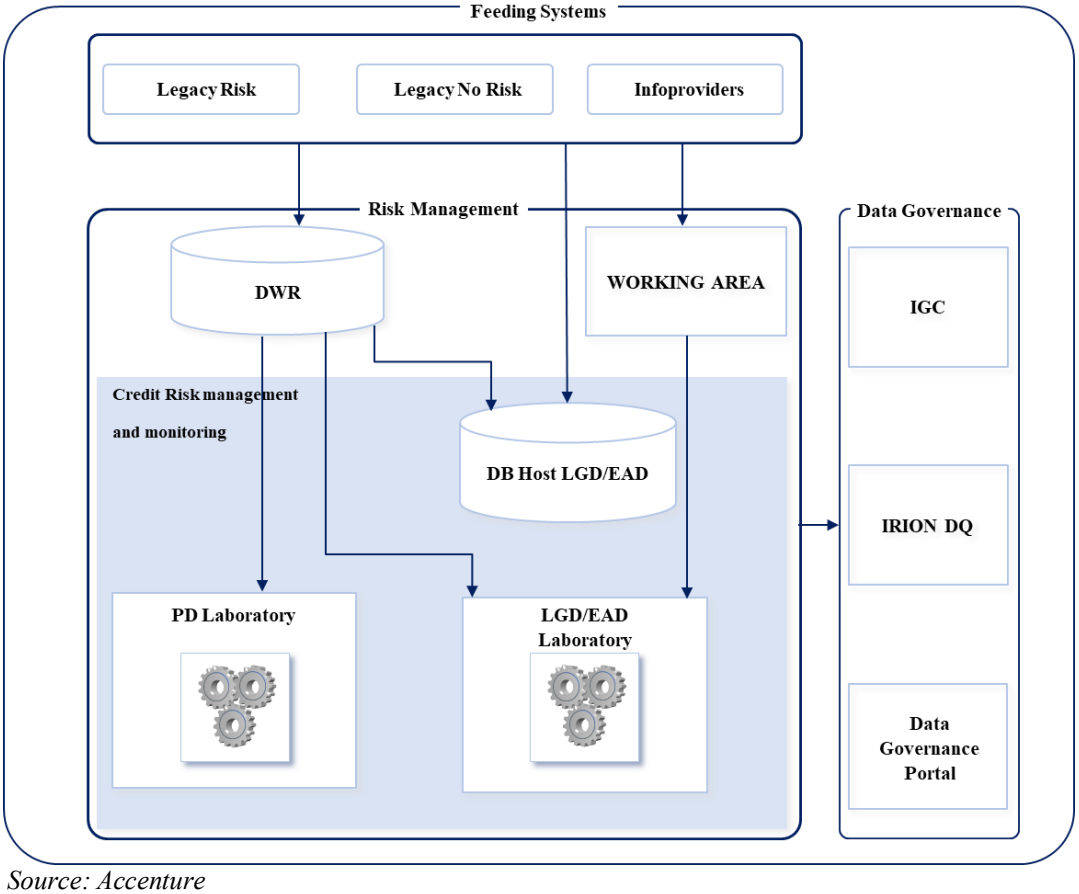


5.3. TRIM Data Quality Credit Risk deliverables

5.3.1. Architectural model of PD and LGD/EAD Laboratory

In the previous paragraph I described in general terms project deliverables; now, before looking at them in more detail, it is necessary to examine in architectural terms the processes leading to PD and LGD/EAD models estimation, showed in Figure 12.

Figure 12: High-level architecture of PD and LGD/EAD Laboratory's feeding processes



Source: Accenture

The high-level architecture describes the entire end-to-end life cycle of the data from the phase of information acquisition by the legacies (Golden source). These feeding points are classified in Legacy

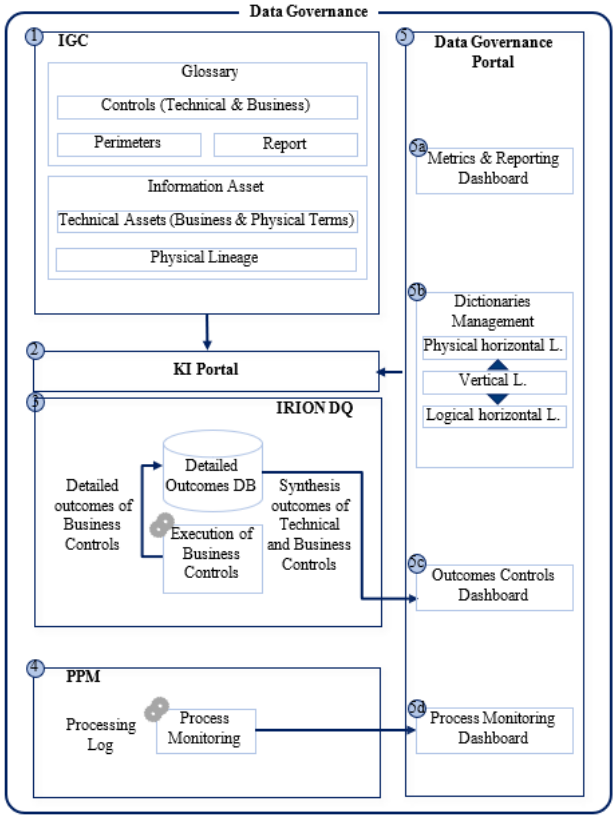
Risk for information belonging to the Risk Management or No Risk for information outside Risk Management. Infoproviders, instead, refer to large systems external to bank providing information useful for PD and LGD/AED models estimation (e.g., credit rating agencies).

The Risk Data Warehouse ("DWR"), the DB Host LGD/EAD and the Working Ares are storages containing the database useful for the calculation of the institution's risk metrics. They belong to the pre-processing phase, during which pre-processing is conducted on the basic data acquired by the feeding systems in order to generate data useful for launching the calculation engines.

PD and LGD/EAD Laboratory are part of the engine phase, during which the risk metrics are calculated. In detail, PD Laboratory receives 210 flows as input from the DWR, of which the 66% is subject to pre-treatments, while the remaining 34% passes without being subject to transformations. In the PD Laboratory users performs the activities of data mining, defining the statistical samples for application test and validation of the models. Users perform the activities of PD modelling and monitoring from the samples previously defined. Any software and documentation supporting the estimation of the model are made available to other users in a dedicated repository. LGD/EAD Laboratory receives in total 265 flows as input. The 32% of the 115 flows acquired from the DB Host LGD/EAD is subject to pre-treatments, while the remaining 68% passes without being subject to transformations. The 27% of the 145 flows acquired from the DWR is subject to pre-treatments, while the remaining 73% passes without being subject to transformations. All the 5 flows acquired from the Working Area pass without being subject to transformations. The LGD/EAD Laboratory allows to process historical data, to select a significant data sample and to estimate the LGD/EAD models with the help of specific statistical tools. The generated LGD/EAD grids are transmitted on demand to the users' applications (i.e., applications used to compute RWA). The software and the official documentation in support of the model's estimation activity are made available to the other users in a dedicated repository.

Looking at the Data Governance portion in more detail is essential to deeply understand the deliverables of the project. Figure 13 highlights the component regarding the Data Governance tools.

Figure 13: Data Governance tools



Source: Accenture

The following describes the main characteristics of the supporting Data Governance tools:

1. IGC: the Information Governance Catalog tool represents the target Repository of the company's information assets in terms of data Information Structures, associated metadata[54] and physical data lineage. This Repository or Catalogue consists of:

    - Assets Glossary: business terms and physical terms, categories, information governance policies and information governance rules;
    - Information assets: technical assets (e.g., database tables).

By using this information, the tool is able to reconstruct the path that the data follow through the technical transformation chain (physical lineage).

2. Portal KI: the tool, integrated with the IGC Dictionary, represents the Repository of the company's main data and reports[55].

[54] Metadata: Information asset that describes a set of data.

[55] Report: Representation of risk metrics aimed at providing the Top Management with data required to effectively support decision-making processes and to consciously manage risk exposure.

3. IRION: with regard to Risk Data Governance, the tool is used as a repository for the detailed results of the technical and business controls, for the implementation of business controls (excluding those controls embedded in the software), and to enable visualisation of the synthesis outcomes through the Outcomes Controls Dashboard.

4. PPM: the Production Processes Monitor tool enables monitoring of the timeliness of the various phases[56] of a process[57]. The operating logic is the following:

   - The atomic element subject to monitoring is the flow (data files), identified by the flow code and the reference period of the flow;
   - The monitoring of the process is subdivided into phases or steps, for which a cut-off (technical or according to business logics) is declared, indicating the overall execution duration;
   - The PPM Engine detects the date and time when the process step was actually completed (actual date) and calculates any delay with regard to the declared cut-off;
   - The following set of values, which takes the name of PPM events, is stored: flow code, flow reference period, cut-off, actual date, delay.

5. Data Governance Portal: single dashboard tool which:
   5.1. Enables monitoring of the outcomes of the controls and timeliness of the processes;
   5.2. Integrates other governance tools such as the IGC dictionary, PPM, KI Portal;
   5.3. Enables (logical/physical) management of the metadata;
   5.4. Implements the calculation of standard metrics.

   5.4.1. Metrics & Reporting Dashboard: engine for calculating the metrics dedicated to the visualisation and monitoring of the Key Quality Indicators;
   5.4.2. Dictionaries Management: tool used to manage the metadata accompanying the monitored processes and to represent the physical horizontal lineage (i.e., relation among Physical Data[58]), vertical lineage (i.e., relation / connection among a Business Data[59] and its single or multiple underlying Physical Data) and logical horizontal lineage (source / target relation among Business Data);
   5.4.3. Outcomes Controls Dashboard: tool used to monitor the execution and the outcome given by each control of the data quality framework. Specifically, this tool makes it possible to interface with the dictionaries; to open tickets and supporting documents connected with the outcome; starting from a primary dimension which lists a series of macro-areas, to conduct the progressive drill-down on the data until the analysis of the individual control, in fact, from the Outcomes Controls Dashboard, which shows the summary statistics for each

[56] Phases: Functional parts allowing to breakdown the process into homogeneous data treatment steps.
[57] Process: Logical sequence of one or multiple transformations applied to data (including activities dedicated to reorganizing information assets) aimed at obtaining one or more final outputs (so-called Process Purposes).
[58] Physical Data: Physical manifestation connected to the Business Data (technical assets).

[59] Business Data: Data expressed in functional terms.

control, it is possible to access the Detailed Outcomes application to get analytical information for drill down purposes;

5.4.4. Process Monitoring Dashboard: tool used to monitor timeliness both from a technical point of view and according to business logics to be able to assess the availability and usability of the information assets at different architectural levels, including for the feeding of the Chain. The monitoring of the flows is conducted by using PPM events as basic data, which highlight the receipts/uploads to the monitored systems.

5.3.2. Data Quality controls

Following the findings identified by the JST ("Bank hasn't provided the evidence of the set of controls that are going to be executed periodically in all the relevant stages of the data cycle"), it was reputed necessary to ensure an end-to-end monitoring of the systems feeding the PD and LGD/EAD Laboratory. Specifically, this implied the definition of a minimum set of controls aimed at guaranteeing a sufficient level of data quality. For enhancing and implementing both technical and business controls, the user within the IT development structure and through the support of Data and Reporting Governance standard tools has to carry out the following steps:

1. Formalisation of a requirement by the business owner (this step only exists in case of business controls);
2. Dictionarisation of technical assets, with the aim of describing the data on which the control is implemented, the specific control rule, the type of control that has been performed;
3. Implementation of controls carried out by the technological application structures of reference along with the support provided by technological structures in charge of Data Governance monitoring;
4. Control outcome storage; once the controls have been implemented the detailed outcomes must be sent to the central repository where they are stored in historical order;
5. Activation of data quality monitoring dashboard;
6. Authorisation to the production of synthesis reporting.

In order to ensure an adequate level of data quality and also the independence of the entities with regard to the identification and implementation of technical and business controls, it is possible to create controls both at feeding systems and at pre-processing level. Controls may be conducted according to the following procedures:

- Embedded in the software**:** these are the controls conducted directly by the calculation processes at the same time as the processing. This category covers all technical controls and business controls within the calculator;
- External Irion engine**:** this includes all business controls conducted by Irion once the processing is concluded.

The negative outcomes of the test of the controls may be of two types:

- KO: a record which has not passed a validity check and will be discarded;

- Warning: a record which has not passed a validity check but will not be deleted since it might become valid in the future or the settings which make it invalid might be modified.

For these outcomes, it will be necessary to store the detailed individual cases. A negative outcome of the technical controls aimed at verifying the quality of the input flow triggers rejection of the entire record. It is also possible to request technical controls that do not trigger rejection. In both cases, it is necessary to send the outcome of the controls to Irion.

Types of technical controls

Each technical control may belong to one of the following types:

- Data balancing: verification that the number of records read in the input file matches the number of records uploaded plus the number of records rejected. If the control fails, the entire file will not be processed. It satisfies the quality criterion of coverage;
- Verification of correct record structure: verification that the record has the envisaged structure (number of fields, length of fields). It satisfies the quality criterion of coverage;
- Data format verification: verification that the format is consistent with the declared data type (e.g., verification that a numerical field contains a number or verification that a date field contains a valid date in the required format). It satisfies the quality criterion of coherence;
- Field completion verification**: v**erification that the field has been compiled as expected (e.g. key fields cannot be <NULL>). It satisfies the quality criterion of existence;
- Verification of presence of duplicate primary key: verification that the flow does not contain records with duplicate key fields. It satisfies the quality criterion of consistency;
- Domain verification: verification that there is referential integrity in the field with respect to a domain table or a defined set of values. It satisfies the quality criterion of coherence;
- Referential Integrity verification: verification that referential integrity is present in the field according to the data model defined. It satisfies the quality criterion of coherence;
- Conditional Referential Integrity verification: it is a Referential Integrity control with a condition aimed at excluding a set of instances based on 'fictitious' values (e.g., do not consider the values '9999999' or 'XXXXXXX'). It satisfies the quality criterion of coherence.

Types of business controls

The business controls are planned by the Data Office/Data Owner who is responsible for business and functional aspects.

- Consistency Controls: aimed at verifying the compatibility of information present in the same information unit (e.g. same flow or same table). This criterion also determines the absence of unintended data duplicates. The following shows the ad hoc controls applicable for different areas of analysis:
  - Credit lines: verification that the approval date is not later than the reference date of the operation;

- Collaterals: verification of the discrepancy between the fair value of collaterals (e.g., mortgages and securities pledges) and the book value recognised at the time of acquisition;
- Current Accounts: verification that numbers have not been calculated for non-interest-bearing current accounts. Verification that the account balance at time T is equal to the sum of the account balance at time T-1 and debit and credit transactions during the period;
- Records: verification of coherence between the province/country code and the sector of economic activity;
- Securities: verification that, if the security is in foreign currency, the nominal value in euro is equal to the equivalent at the end-of-month exchange rate of the nominal value in foreign currency.

- Coherence Controls (Cross-functional): **a**imed at verifying the compatibility of information in two different information units (e.g. input flow and system table) related to each other. The following shows the ad hoc controls applicable for different areas of analysis:
  - Loans: control between the type of product and type of guarantee that backs it (e.g., the mortgage loan must be associated with a guarantee number which has the technical form of mortgage, and the same for unsecured loans and sureties received);
  - Current accounts: control between the income statement items (e.g., account holding fees) and what is contained in the set of conditions for the specific agreement code associated with the account;
  - Derivatives: control of coherence between type of contract and type of counterparty for OTC derivative contracts;
  - Credit lines: control that the account codes associated with the credit line codes have been correctly entered;
  - Record: control between the type of counterparty and type of product.
- Stability or Relevance Controls: aimed at verifying the oscillation of the data within the limits of an expected variation range. This type of controls, better identified as 'trend' controls, should be considered residual with respect to the types described above for the following reasons:
  - They do not give certain and specific anomaly points, but identify the discrepancy from the historical trend of the data;
  - The expected variation thresholds, when not properly updated with respect to business trends, may lead to inaccurate predictions.

Specific non-applicability rules per criterion

During the controls planning phase, situations where the quality criterion is not applicable may occur. Details of these conditions are provided as follows:

- Certifiability Control: the Non-Applicability of Certifiability may be declared in the following cases:
  - When there is no Master information (as the data is calculated by the same process subject to analysis);
  - When data that is being analysed comes directly from the Master source;

- Consistency Control: the Non-Applicability of Consistency occurs only in cases where the information Table does not contain related information from a business point of view that may be used to make comparisons;
- Coherence Control: the Non-Applicability of Coherence occurs only in cases where there is no related information (not even within a process different from that subject to analysis) from a business point of view that can be used to make comparisons;
- Stability Controls: stability is considered as non-applicable for amounts where it is impossible to measure the variation from one period to another;
- Existence Controls: the Non-Applicability of Existence occurs in the following cases:
  - When it is possible that no value has been assigned to the data;
  - When the data, although no existence control is being conducted, has always a value assigned (even the default value);
- Coverage Controls: coverage is considered not applicable only for fields where it is not possible to test the receipt of all cases, or where the number of occurrences expected is not known beforehand.

As already said, the controls aim at strengthening the Data Governance framework along the entire data lineage. For this reason, they were implemented both by Legacies, which represent the native systems, PD chain, which includes DWR and PD Laboratory, and LGD/EAD chain, which embraces DB Host and LGD/EAD Laboratory (Working Area has been excluded since it does not conduct pre-processing on the data). Controls were performed on current data (data of 2018-12019) and on available data of the last three years (2015-2016-2017). The TRIM Data Quality Credit Risk Project for Obligation #4 delivered a new set of business and technical controls by August 31, as Table 5 shows.

Table 5: Number of technical and business controls implemented for Obligation #4

	Legacy Risk	Legacy No Risk	PD Chain	LGD/EAD Chain	Total
Business controls	29	67	216		312
Technical controls	85	220	376	146	827
Total	114	287	738		1139

Source: Accenture

Additional controls will be implemented in order to extend the Data Governance infrastructure in line with the findings formalised within the Obligation #7 related to the TRIM SME Corporate on-site inspection.

Controls' results were monitored and managed by the task force within the Project, that, after analysing controls' outcomes, performed fine tuning activities on control algorithms and, where necessary, remediation activities on data, traced by opening incident tickets; this remediation process will be detailed in the next paragraph.

5.3.3. Organisational processes and Remediation

Among the gaps identified by the Obligation #4, there was the lack of an effective data quality organisational process. In order to be compliant to Supervisor requests, DQ Credit Risk TRIM Project formalised organisational processes such as «Anomalies remediation and escalation», which aims to rule the remediation and escalation actions arising from both technical and business controls, identifying the owner in charge to monitor control outcomes, and «Control data lifecycle management», which introduces the control definition, the implementation and the registration on a dedicated dictionary.

Moreover, a monitoring workflow of PD and LGD/EAD Laboratory feeding was defined. It started from September 2019 acting on data referred to August 31 with the objective to grant:

- The monitoring of the prompt feeding of Governance Systems (DWR / DB Host) from Legacies systems;
- The promptness and completeness of control outcomes, collected on data quality tools;
- The continuous monitoring of the outcomes arising from control performing;
- The address of remediation and escalation activities which includes the anomalies tracking (adoption of the Group ticketing system) and the empowerment of Control Room role.

Later (within September 2020), as part of the project put in place to fill the gaps highlighted by the findings of TRIM SME Corporate Obligation #7, the former adopted solution will be further strengthened ("Strengthening Solution"). More in detail, an extension of the overseeing is expected, and it will focus on:

- The monitoring of the promptness of flows and outcomes, automated and available on DQ tools;
- The development of a structured evidence that the control outcomes, both at Legacy and Governance Systems level, are continuously monitored by the identified control owner.

Specifically, the monitoring workflow of the PD and LGD/EAD Laboratory feeding consists of two main phases:

- The monitoring performed from a technical point of view (owner DTOW):
  - The promptness of feeding in comparison to the expected sending cut-offs;
  - The continuous analysis of the outcomes arising from the foreseen technical controls performing;
  - In case of detected errors, the remediation process is started through the Group ticketing system in order to track the anomaly and the related solving actions;
  - The start of the escalation procedure in those cases where the remediation activities seem not to be enough to solve the problem.
- The monitoring performed from a business point of view (owner DOW):
  - The continuous analysis of the outcomes arising from the foreseen business controls performing;

- In case of detected errors, the remediation process is started through the Group ticketing system in order to track the anomaly and the related solving actions;
- The start of the escalation procedure in those cases where the remediation activities seem not to be enough to solve the problem.

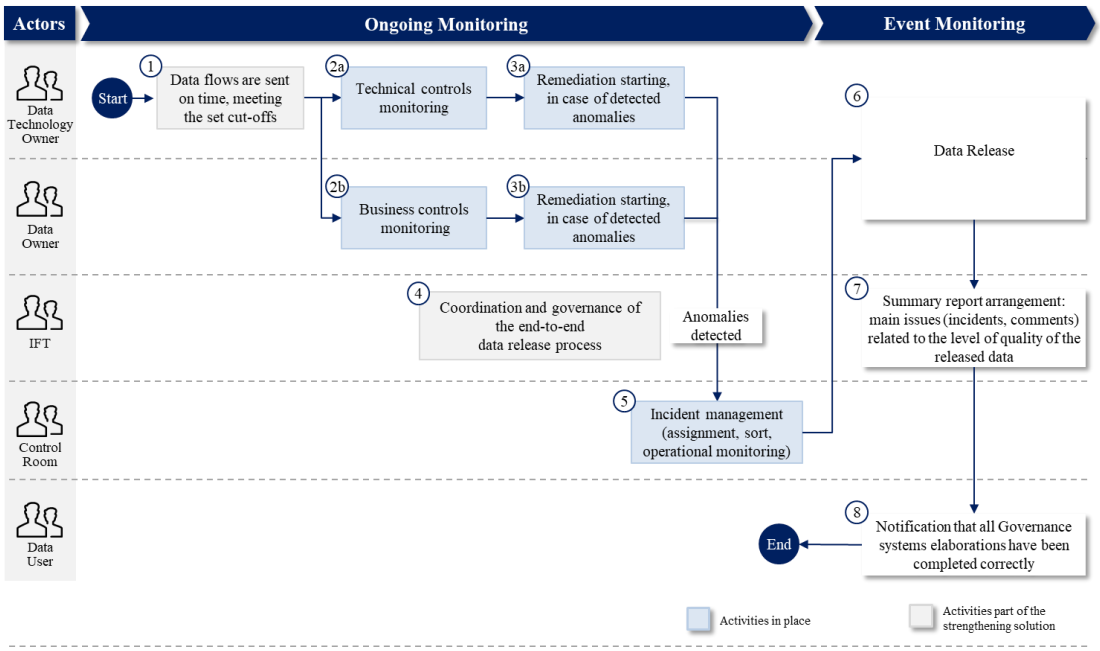
Thus, as part of the monitoring workflow, the official data remediation channel was activated through the establishment of a Control Room aimed to manage and address the requests concerning anomalies that the technology / business users might observe during the activities of process monitoring and execution of controls. In particular, the remediation process consists of incident opening (including the detailed description and the cluster of belonging), assignment of the pending incidents by the Control Room to the competent organisational unit, and diary of all actions which have been put in place.

The strengthening solution will be implemented later, and it will consist of:

- Improvements of the tools already in support to the mentioned phases;
- The empowerment of the Interfunctional team which will be in charge to grant coordination and governance on the whole workflow. The Interfunctional team (IFT) consists of organisational units which are part of the Data Office Department, Operations Department and IT Services Department (the Control Room is included). The IFT aims to:
  - Verify and make certain of continuous monitoring performed by the DTOW / DOW, as foreseen by the set workflow;
  - Collect evidences from all the involved actors concerning relevant detected deficiencies;
  - Ascertain that every action has been put in place in order to solve the detected anomalies, suggest solutions and improvements, monitor the effective resolution;
  - Ease and support escalation procedures in case they need to be started;
  - Report to the DUS about the state of the art of the data release and their quality level;
- The extension of the overseeing on the phases related to data release and post data release to the governance systems.

Figure 14 describes the activities and roles in terms of data ownership, as foreseen by the monitoring workflow of governance systems feeding.

Figure 14: Monitoring workflow's activities and roles



Source: Accenture

5.3.4. Data Quality Tools

Another gap formalised by the ECB through the Obligation #4 referred to the lack of a standard report providing a general overview of the performance in terms of data quality; indeed, the bank was required to monitor the compliance with the defined data quality objectives by means of a comprehensive system of data quality indicators and corresponding thresholds. In order to address this shortcoming, an IRB data quality dedicated report providing a comprehensive view of the quality of data along the IRB data chain was developed.

In this context, the Data Quality Report allows to:

- Measure through synthetic indicators the level of IRB data quality detected by the controls' framework;
- Monitor the data quality indicators values by means of the corresponding thresholds.

KQIs (Key Quality Indicators) are synthetic indicators representing the data quality level and, if adjusted at different level of synthesis and detail, may serve both strategic and operating purposes. KQIs are indicators expressing variables useful for representing key phenomena of general interest, which can contribute to provide a summary overview of the state of data quality. KQIs have the following characteristics:

- They are indicators measurable in a numerical and objective way;
- They enable to monitor information which plays a key role in relation to the reference business;
- They are comparable to a target or benchmark value where possible (in order to measure performance).

KQIs allow, therefore, to synthetically represent the quality of company's data, but also to summarise the results related to the data quality processes (e.g., outcomes of the performed controls, activities aimed at the resolution of anomalies), providing an overview of the data quality level.

KQIs can be defined and monitored for a given scope of data (e.g., for a specific informational are of competence) with the objective to monitor particular issues or events, or to collect evidences on the quality of the whole data, developing synthetic representations.

Specifically, two types of data quality indicators were adopted by the bank:

- Coverage indicator: this indicator highlights the level of completeness of the database on which technical and business controls are performed;
- Defectiveness indicator: this indicator represents the degree of defectiveness related to performed controls.

Thresholds allow monitoring the observed values of the KQIs and highlighting significant deviations due to defects detected by the controls.

Starting from September 2019, the Data Quality Report allows the monitoring of the KQIs according to the following process.

- Calculation of the KQIs: the execution of the structural controls enables the calculation of the KQIs. The calculation is performed by the Metrics Engine, i.e. the engine of the Key Quality Indicators;
- Operational monitoring: the consultation of the KQIs takes place through a specific report (i.e. the Data Quality Report) available at the Data Governance Portal, the bank's tool for monitoring data quality processes. The figures responsible for Data Ownership (Data Owners, Data Technology Owners) monitor the trend of data quality for the areas of competence. The application of thresholds will highlight any deterioration in quality and may guide the definition of improvement actions to bring the quality back to the acceptable levels;
- Strategic reporting: the monitoring of the Data Quality Report will allow a formal reporting process on the quality of risk data for the senior management. The Data Office will analyse the monitoring results and encourage Data Governance actors to adopt any necessary improvement action. The KQIs will also be used to measure the effective application of the data governance model.

Moreover, in the perspective of data quality analysis, KQIs allow to perform analysis of the following types:

- Descriptive: the purpose is to represent the trend of data quality over time, enabling to display the obtained results;
- Diagnostic: the goal is to identify the reasons underlying given trends or events in order to define the most effective actions and optimise the inefficiencies which led to the detected results;

- Predictive: the aim is to forecast the trends of the variables of interest in the light of the observed historical data;
- Prescriptive: the objective is to suppose a general future scenario on data quality (What-If Analysis).

CHAPTER 6 – QUANTITATIVE ANALYSIS OF DATA QUALITY VARIATION

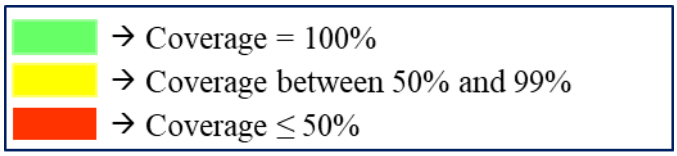
6.1. Objective of the analysis and procedure followed

By using the data quality indicators defined in the previous chapter, I decided to perform an analysis of the data quality used by the banking group for PD, LGD and EAD models estimation. The purpose of this study was specifically to investigate whether the data governance framework implemented through the TRIM Data Quality Credit Risk project actually led to an improvement in the quality of those data.

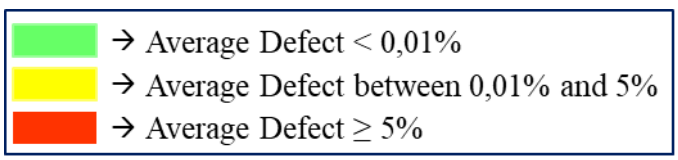
The starting dataset used to conduct the analysis is constituted by the report of the synthesis outcomes of all types of technical and business controls described in the previous chapter, available at the Outcomes Controls Dashboard in the Data Governance Portal. Controls' outcomes are related to data having reference date from January 2015 until August 2019 because, even though controls were implemented starting from September 2018, they were reperformed on data of 2015, 2016, 2017 and previous months of 2018.

On these available data, KQIs defined before were computed.

- Coverage indicator, which highlights the level of completeness of the database on which technical and business controls are performed.
  - Calculation rule: the indicator is calculated with reference to all categories of control and every table as the ratio between the number of performed controls and the overall number of expected controls per period (i.e., day, month, quarter). Missing data are detected by observing the absence of the outcome of the controls connected to them in the report of the synthesis controls' outcomes.



- Defectiveness indicator (average defect), which represents the degree of defectiveness related to performed controls.
  - Calculation rule: the indicator is calculated on annual basis for each table and control's category of control, as the ratio between the sum of total defects and the sum of the total cases analysed per period (i.e., day, month, quarter). Defects are represented by the sum of KO and warnings recorded in the report of the synthesis controls' outcomes.



The controls are related to tables, meant as information structures containing data of varied typologies useful for PD, LGD and EAD models estimation. Although the inclusion in the dataset of the whole perimeter of tables used for credit risk's metrics estimation, for the purpose of the analysis it was decided to focus only on a subset of tables, characterised by a substantial deviation of the KQIs from their initial value. It was not considered useful to cite tables whose data already presented the maximum quality, thus, not exhibiting significant evidences during the computation of the KQIs.

The calculation frequency of the KQIs is directly correlated to the controls' periodicity (i.e., daily, monthly, quarterly), which, in turn, depends on the update frequency of the data to which the controls are referred.

The analysis was composed of two phases:

1. Calculation of the KQIs per each reference period (i.e., day, month, quarter) of the controls related to a given table, in order to represent their trend over time. With the aim of providing a higher-level view, the average value of the KQIs for the years in question was calculated and their evolution over the years was showed;
2. Execution of the Mann-Whitney U Test, by considering each KQI of a given table referred to a certain competence period, in order to examine whether the difference in the data quality pre and post project initiation was statistically significant and possibly to quantify it.

6.2. Statistical methodology adopted

6.2.1. Introduction to parametric and nonparametric tests

Before describing the Mann-Whitney U Test (and the equivalent Wilcoxon-Mann-Whitney Test), an overview of the hypothesis testing, focusing particularly on the differences characterising parametric and nonparametric tests, is provided; for additional information see *Probabilità e statistica per le scienze e l'ingegneria*, (2008).

Generally, the very interesting aspect is the interpretation of data, rather than data alone. Data can be interpreted by assuming a specific structure or outcome and use statistical methods to confirm or reject the assumption; the statistical tests used for this purpose are called statistical hypothesis tests. In statistics, a hypothesis test calculates some quantity under a given assumption. The result of the test allows to interpret whether the assumption holds or whether the assumption has been violated.

There are two types of statistical tests which can be used:

- Parametric tests assume underlying statistical distributions in the data. Therefore, several conditions of validity must be met so that the result of a parametric test is reliable. The advantage of using a parametric test instead of a nonparametric equivalent is that the former will have more statistical power than the latter. In other words, a parametric test is more able to lead to a rejection of H_0; indeed, most of the time, the p-value associated to a parametric test will be lower than the p-value associated to a nonparametric equivalent that is run on the same data;

- Nonparametric tests, also called distribution free tests, do not rely on any distribution. They can thus be applied even if parametric conditions of validity are not met. Nonparametric tests are more robust than parametric tests. In other words, they are valid in a broader range of situations (fewer conditions of validity).

The fundamental differences between parametric and nonparametric test are discussed in the following points:

- A statistical test in which specific assumptions are made about the population parameter is known as the parametric test. A statistical test used in the case of non-metric independent variables is called nonparametric test;
- In the parametric test, the test statistic is based on distribution. On the other hand, the test statistic is arbitrary in the case of the nonparametric test;
- In the parametric test, it is assumed that the measurement of variables of interest is done on interval or ratio level. As opposed to the nonparametric test, wherein the variables of interest are measured on nominal or ordinal scale;
- In general, the measure of central tendency in the parametric test is mean, while in the case of the nonparametric test is median;
- In the parametric test, there is complete information about the population. Conversely, in the nonparametric test, there is no information about the population;
- The applicability of parametric test is for variables only, whereas nonparametric test applies to both variables and attributes.

6.2.2. Description of Wilcoxon-Mann-Whitney Test and Mann-Whitney U Test

Wilcoxon-Mann-Whitney Test and Mann-Whitney U Test are two equivalent nonparametric tests which can be used for the same purpose, that is assessing whether two samples were selected from populations having the same distribution, and given certain assumptions, have the same median. The tests are based on the following assumptions:

- Random samples from populations;
- Independence within samples and mutual independence between samples;
- Measurement scale at least ordinal;
- If used as a test of dominance, no distributional assumptions; if used to compare medians, similar shape for the two distributions.

The following hypothesis are tested:

- H_0: the distributions of both populations are equal
- H_1: the distributions of both populations are not equal.

Wilcoxon-Mann-Whitney Test

Wilcoxon-Mann-Whitney Test is based on the sum of samples' ranks. The methodology can be decomposed in the following steps:

1. Combine the data of the two groups in a single series, arranging the values in ascending order. For each data, keep track of the sample to which it belongs;
2. Define n_1 the size of the smaller group, n_2 the size of the larger group. Rank each value in the combined series composed of the two samples;
3. Add up the ranks of the data from the smaller sample and name it T;

4.1. In case of small samples (n_1 and $n_2 \leq 10$), look up p-value from tables of Wilcoxon's sum of ranks statistics and use it to accept or reject the null hypothesis;

4.2. In case of large samples (n_1 or $n_2 > 10$), T statistic is approximately normally distributed. Significance can therefore be tested by the standard normal distribution with a mean of zero and standard deviation of 1. Z estimation formula, adjusted with the continuity correction c (c is 0,5 or - 0,5 depending on the nature of the test) in order to increase the quality of the approximation, is the following:

$$Z = \frac{(T + c) - \mu_T}{\sigma_T}$$

where:

- mean μ_T is given by $\mu_T = \frac{n_1 \times (n_1 + n_2 + 1)}{2}$

- standard deviation σ_T is given by $\sigma_T = \sqrt{\frac{n_1 \times n_2 \times (n_1 + n_2 + 1)}{12}}$

Thus, look up p-value from standard normal tables and use it to accept or reject the null hypothesis.

When there are ties (ex-aequo observations) between the values in the two samples, the rank assigned to the tied values is the mean of unadjusted rankings (e.g., the ranks of {3, 5, 5, 5, 5, 8} are {1, 3.5, 3.5, 3.5, 3.5, 6}, while the unadjusted rank would be {1, 2, 3, 4, 5, 6}). The mean μ_T remains unchanged, but the standard deviation σ_T is lower; therefore, it must be corrected and becomes

$$\sigma_T = \sqrt{\frac{n_1 \times n_2}{N \times (N-1)} \times \left(\frac{N^3 - N}{12} - \sum T_i \right)}$$

where:

- $N = n_1 + n_2$

- $T_i = \frac{t_i^3 - t_i}{12}$ with t_i = number of ex-aequo observations of the same rank

Ties correction reduces standard deviation value and, therefore, increases Z value.

Mann-Whitney U Test

Mann-Whitney U Test is based on the count of precedences between samples' values. The computation of U statistic can occur with two different methodologies.

Direct method:

1. Combine the data of the two groups in a single series, arranging the values in ascending order. For each data, keep track of the sample to which it belongs;
2. Count the number of precedences, that is how many times each data in a group is preceded by data from the other group. Add up the total number of precedences for each sample;
3. Name U the lowest between the two values computed. The other value U' is then given by $U' = (n_1 \times n_2) - U$.

Indirect method:

1. Combine the data of the two groups in a single series, arranging the values in ascending order. For each data, keep track of the sample to which it belongs;
2. Define n_1 the size of the smaller group, n_2 the size of the larger group. Rank each value in the combined series composed of the two samples;
3. Add up the ranks of the data from the smaller sample and name it T;
4. Calculate $U = T - \frac{n_1 \times (n_1+1)}{2}$.

For both methods:

5.1. In case of small samples (n_1 and $n_2 \leq 15$), look up p-value from Mann-Whitney tables and use it to accept or reject the null hypothesis;

5.2. In case of large samples (n_1 or $n_2 > 15$), U statistic is approximately normally distributed. Significance can therefore be tested by the standard normal distribution with a mean of zero and standard deviation of 1. Z estimation formula, adjusted with the continuity correction c (c is 0,5 or - 0,5 depending on the nature of the test) in order to increase the quality of the approximation, is the following:

$$Z = \frac{(U + c) - \mu_U}{\sigma_U}$$

where:

- mean μ_U is given by $\mu_U = \frac{n_1 \times n_2}{2}$

- standard deviation σ_U is given by $\sigma_U = \sqrt{\frac{n_1 \times n_2 \times (n_1 + n_2 + 1)}{12}}$

Thus, look up p-value from standard normal tables and use it to accept or reject the null hypothesis.

When there are ties (ex-aequo observations) between the values in the two samples, the rank assigned to the tied values is the mean of unadjusted rankings. The mean μ_U remains unchanged, but the standard deviation σ_U is lower; therefore, it must be corrected and becomes

$$\sigma_U = \sqrt{\frac{n_1 \times n_2}{N \times (N-1)} \times \left(\frac{N^3 - N}{12} - \sum T_i \right)}$$

where:

- $N = n_1 + n_2$

- $T_i = \frac{t_i^3 - t_i}{12}$ with t_i = number of ex-aequo observations of the same rank

Ties correction reduces standard deviation value and, therefore, increases Z value.

6.3. Presentation of the analysis performed and its results

In this section the results of the analysis performed for each table, containing data useful for the estimation of PD, LGD and EAD models for the banking group in question, are presented. Tables are generally referred to as Table 1, Table 2 and so on. For each table the research only focused on KQIs presenting low values at the beginning of the period under assessment (either coverage indicator, defectiveness indicator or both). The reasons underlying low quality are explained and the related remediation actions are exposed. The study is divided into two different parts, with the former only related to information area contributing to PD models estimation and the latter related to information area contributing to LGD and EAD models estimation.

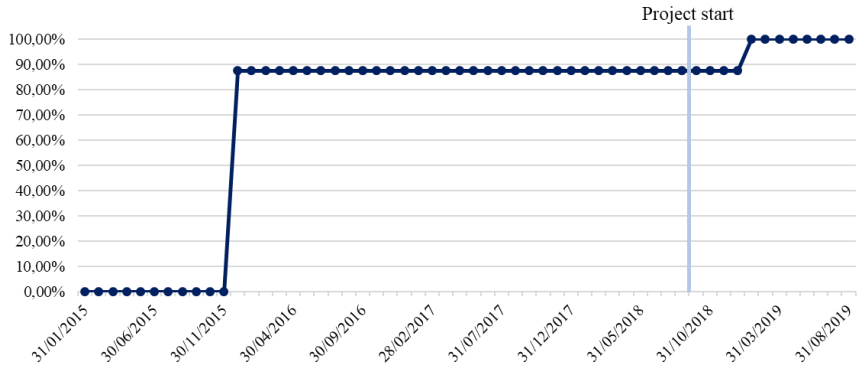
PD models estimation

Table 1 contains the data required for the identification of the customers (CID and Group CID, type of costumers, SAE and RAE codes, residence data, Credit register ID, etc.). The source of these data is the General Register internal application.

Table 1	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Technical	Monthly	8	96	8,33%	100,00%	100,00%	100,00%	100,00%
	Business	Monthly	12	144	100,00%	100,00%	100,00%	100,00%	100,00%

The control's backward compatibility was not allowed, due to the change of feeding since December 2015 (not available file related to January-November 2015).

Table 1 - Coverage indicator (Technical controls)



	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
Table 1	Technical	Amount format	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Date format	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Domain	Monthly	5	60	0,00%	0,00%	0,00%	0,00%	0,00%
		Univocity	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
	Business	Coherency	Monthly	3	36	0,03%	0,00%	0,01%	0,00%	0,00%
		Consistency	Monthly	9	108	0,00%	0,00%	0,00%	0,00%	0,00%

The controls that pointed out defects different from zero were related to feeding issues subject to a technical review with the related source (i.e., General Register). Defects were mainly related to expired counterparties, thus control rules were updated in order to exclude them from the scope of application. In order to do this, a remedy action was addressed with the source system.

Table 1 - Defectiveness indicator (Coherency category)

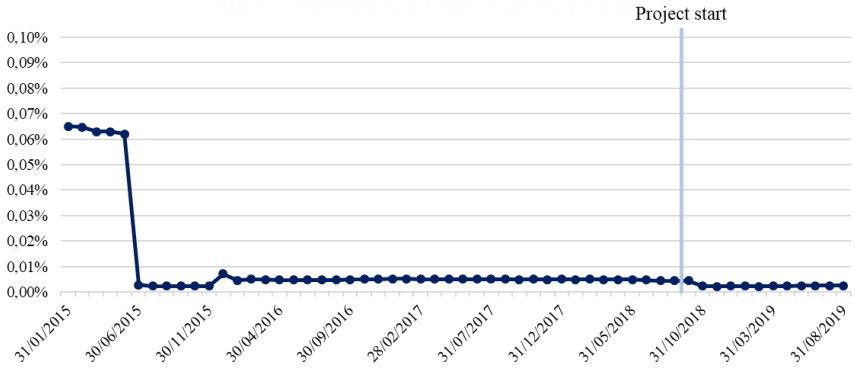


Table 2 is composed by a subset of the data stream quarterly produced by the regulatory capital computation procedure.

	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
Table 2	Technical	Quarterly	6	24	83,33%	83,33%	100,00%	100,00%	100,00%

The control's backward compatibility was not allowed, due to the change of feeding records layout since 2017 (few fields have been added). Low coverage level was only related to the amount format control.

Table 2 - Coverage indicator (Technical controls)

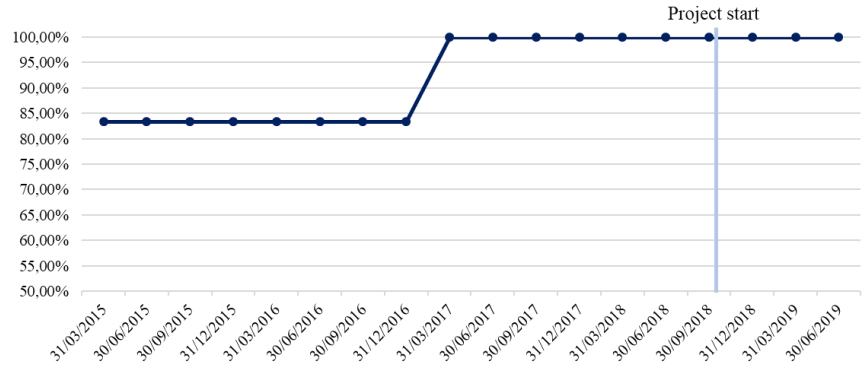


Table 2	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Technical	Amount format	Quarterly	1	4	-	-	0,00%	0,00%	0,00%
		Date format	Quarterly	1	4	0,00%	0,00%	0,00%	0,00%	0,00%
		Domain	Quarterly	3	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Univocity	Quarterly	1	4	0,00%	0,00%	0,00%	0,00%	0,00%

Table 3 is fed by a dataflow coming from the internal application used for the Basel II Capital Requirements' Calculation and contains information about the customer default status (status, default start date, default end date, etc.).

Table 3	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Technical	Monthly	6	72	100,00%	100,00%	100,00%	100,00%	100,00%

Table 3	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Technical	Completeness	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Date format	Monthly	2	24	36,17%	38,30%	9,92%	1,28%	0,05%
		Domain	Monthly	2	24	0,00%	0,00%	0,00%	0,00%	0,00%
		Univocity	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%

Defects were related to a specific field within the table. The remedy actions related to the field itself were addressed after having examined the controls' outcomes.

Table 3 - Defectiveness indicator (Date format category)

Table 4 contains information about internal rating batch for counterparties belonging to the SME Corporate segment.

Table 4	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Technical	Monthly	8	96	100,00%	100,00%	100,00%	100,00%	100,00%

Table 4	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Technical	Amount format	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Completeness	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Date format	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Domain	Monthly	4	48	1,87%	1,79%	1,63%	1,59%	1,40%
		Univocity	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%

The remedy actions with the source system regarding the domains subject to controls were addressed with the aim of safeguarding the updating of the used domains.

Table 4 - Defectiveness indicator (Domain category)

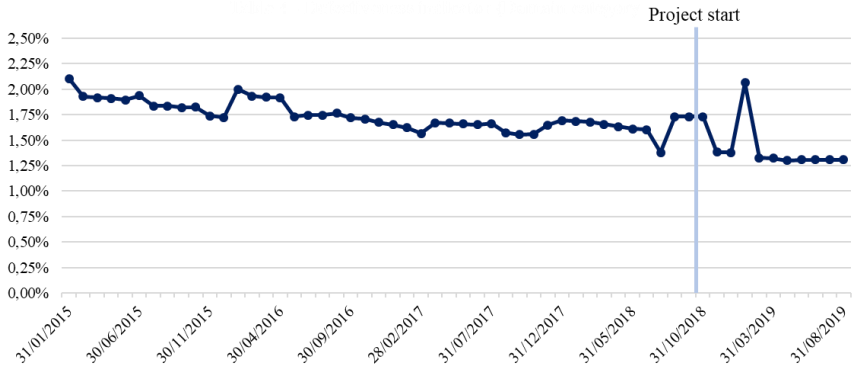


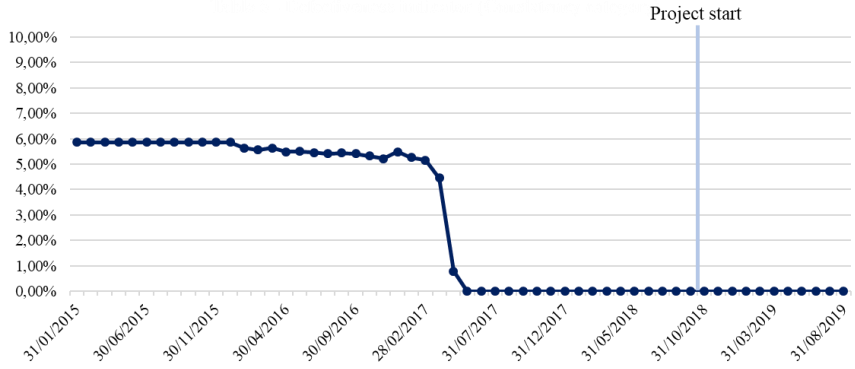
Table 5 contains information about overdraft of counterparties.

Table 5	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Business	Monthly	4	48	100,00%	100,00%	100,00%	100,00%	100,00%

Table 5	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Business	Coherency	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Consistency	Monthly	3	36	5,85%	5,47%	1,30%	0,00%	0,00%

Defects were linked to consistency on fields related to connection between counterparties. A remedy action was implemented.

Table 5 - Defectiveness indicator (Consistency category)



LGD / EAD models estimation

Table 6 contains the information about the account balance acquired from the internal synthesis system used for accounting and supervisory reporting purposes.

Table 6	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Technical	Monthly	3	36	33,33%	100,00%	100,00%	100,00%	100,00%
	Business	Monthly	13	156	100,00%	100,00%	100,00%	100,00%	100,00%

The control's backward compatibility was not allowed, due to the change in the feeding process since September 2015

Table 6 - Coverage indicator (Technical controls)

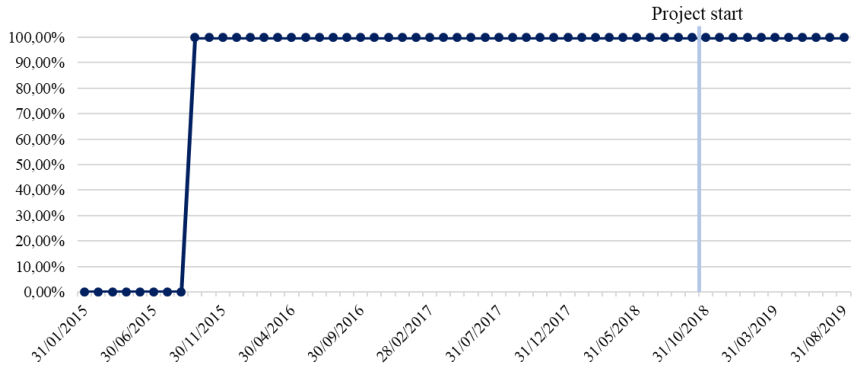


Table 6	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Technical	Amount format	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Date format	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
		Univocity	Monthly	1	12	0,00%	0,00%	0,00%	0,00%	0,00%
	Business	Existence	Monthly	13	156	0,86%	1,95%	0,57%	0,01%	0,01%

The existence control compares the counterparties included in the monthly elaboration of the table (sources of the account balance) with the counterparties included in the perimeter dataflow used to identify only the defaulted obligors. In particular, main defects were related to the inclusion of expired/improper counterparty IDs in the perimeter flow adopted in the data processing steps.

Table 6 - Defectiveness indicator (Existence category)

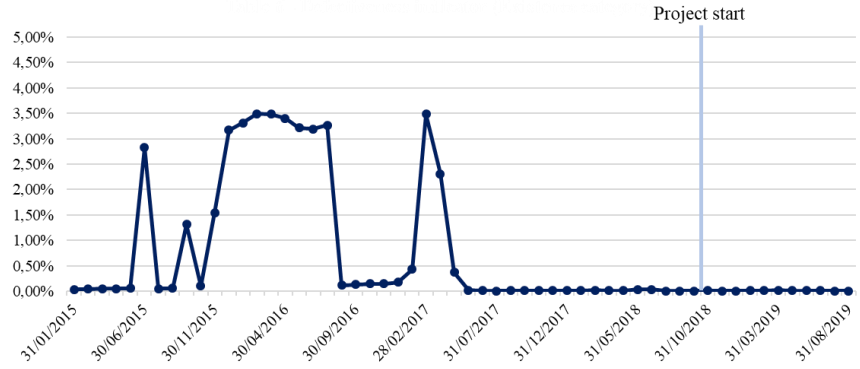


Table 7 is used to administrate long and medium-term loans, both to retail customers and companies. The table manages the whole cycle of the credit facilities and deals about three typologies of financings: mortgages, loans and bills (notes).

Table 7	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Technical	Monthly	7	84	100,00%	100,00%	100,00%	100,00%	100,00%
	Business	Monthly	15	180	100,00%	100,00%	100,00%	100,00%	100,00%

Table 7	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Technical	Completeness	Monthly	3	36	0,00%	0,00%	0,00%	0,00%	0,00%
		Univocity	Monthly	4	48	0,54%	0,48%	0,51%	0,59%	0,07%
	Business	Coherency	Monthly	5	60	0,00%	0,00%	0,00%	0,00%	0,00%
		Coverage	Monthly	5	60	0,00%	0,00%	0,00%	0,00%	0,00%
		Existence	Monthly	5	60	0,00%	0,00%	0,00%	0,00%	0,00%

Defects regarded controls on duplicated key. Since it was necessary to integrate a specific field in the record layout, this action was properly addressed with the legacy system.

Table 7 - Defectiveness indicator (Univocity category)

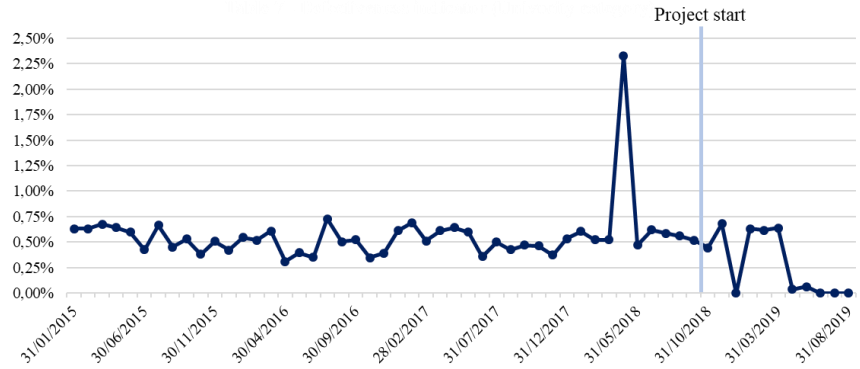


Table 8 is the input source system feeding that provides information's on cash flows from current account.

Table 8	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Technical	Monthly	8	96	100,00%	100,00%	100,00%	100,00%	100,00%
	Business	Monthly	13	156	100,00%	100,00%	100,00%	100,00%	100,00%

Table 8	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Technical	Completeness	Monthly	4	48	0,00%	0,00%	0,00%	0,00%	0,00%
		Univocity	Monthly	4	48	0,16%	0,14%	0,13%	0,09%	0,07%
	Business	Coherency	Monthly	4	48	0,00%	0,00%	0,00%	0,00%	0,00%
		Coverage	Monthly	4	48	0,00%	0,00%	0,00%	0,00%	0,00%
		Existence	Monthly	5	60	0,00%	0,00%	0,00%	0,00%	0,00%

Defects regarded controls on duplicated key. The integration of a specific field in the record layout was addressed with the legacy system.

Table 8 - Defectiveness indicator (Univocity category)

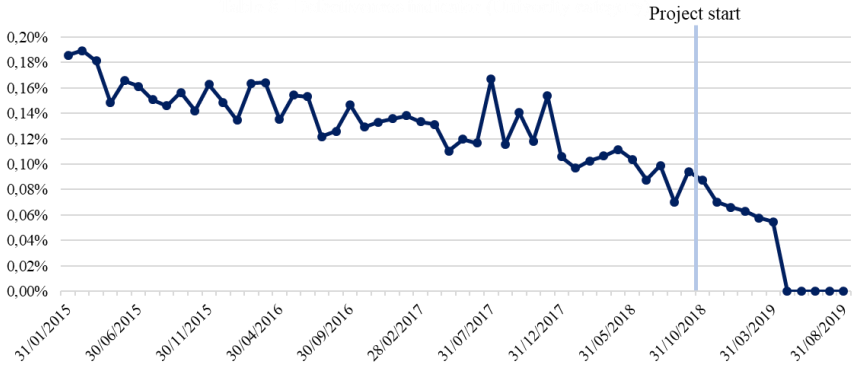


Table 9 is the system aimed at administrating long and medium-term loans characterised by “tailor made” contracts. Borrowers are generally large or medium companies.

Table 9	Type of controls	Frequency	N° of controls	N° of outcomes expected per year	% Coverage 2015	% Coverage 2016	% Coverage 2017	% Coverage 2018	% Coverage 2019
	Technical	Monthly	7	84	100,00%	100,00%	100,00%	100,00%	100,00%
	Business	Monthly	14	168	100,00%	100,00%	100,00%	100,00%	100,00%

Table 9	Type of controls	Category	Frequency	N° of controls	N° of outcomes expected per year	% Average Defect 2015	% Average Defect 2016	% Average Defect 2017	% Average Defect 2018	% Average Defect 2019
	Technical	Completeness	Monthly	3	36	2,79%	3,64%	2,92%	2,78%	0,09%
		Univocity	Monthly	4	48	7,97%	8,90%	12,19%	8,32%	4,15%
	Business	Coherency	Monthly	4	48	0,00%	0,00%	0,00%	0,00%	0,00%
		Coverage	Monthly	5	60	0,00%	0,00%	0,00%	0,00%	0,00%
		Existence	Monthly	5	60	0,00%	0,00%	0,00%	0,00%	0,00%

Defects regarded the uniqueness and the completeness of the input flow’s primary key. Analysis with the source system were carried out in order to identify the proper fields to be integrated in the record layout.

Table 9 - Defectiveness indicator (Completeness category)

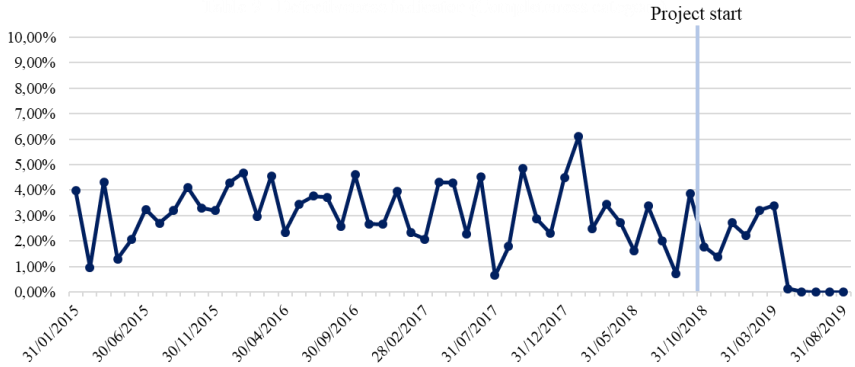


Table 9 - Defectiveness indicator (Univocity category)

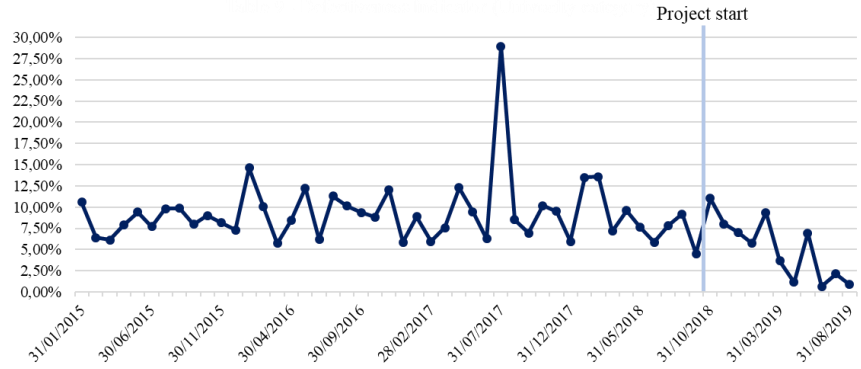


Table 10 is an internal IT system dealing with the management of non-performing loans. For all the counterparties, it stores the related default status (past due, unlikely to pay and bad loan) and all the information regarding the evolution during the entire recovery process, including recovery and management of the information of the write-offs.

	Type of	Frequency	N° of	N° of outcomes expected per	% Coverage	% Coverage	% Coverage	% Coverage	% Coverage
Table 10	**Type of controls**	**Category**	**Frequency**	**N° of controls**	**N° of outcomes expected per year**	**% Average Defect 2015**	**% Average Defect 2016**	**% Average Defect 2017**	**% Average Defect 2018**	**% Average Defect 2019**
	Technical	Completeness	Monthly	4	48	0,61%	0,05%	0,04%	0,01%	0,00%
		Univocity	Monthly	4	48	0,00%	0,00%	0,00%	0,00%	0,00%
	Business	Coherency	Monthly	3	36	0,00%	0,00%	0,00%	0,00%	0,00%
		Coverage	Monthly	4	48	0,00%	0,00%	0,00%	0,00%	0,00%
		Existence	Monthly	4	48	0,56%	0,02%	0,00%	0,07%	0,00%

For the technical completeness controls, defects were related to a missing value in the input flow's primary key. Analysis were carried out in order to identify the correct remedy action jointly with the source system. The business existence controls discarded the records for which all the amounts field were equal to 0. Also in this case analysis were performed with the source system in order to identify the correct remedy action.

Table 10 - Defectiveness indicator (Completeness category)

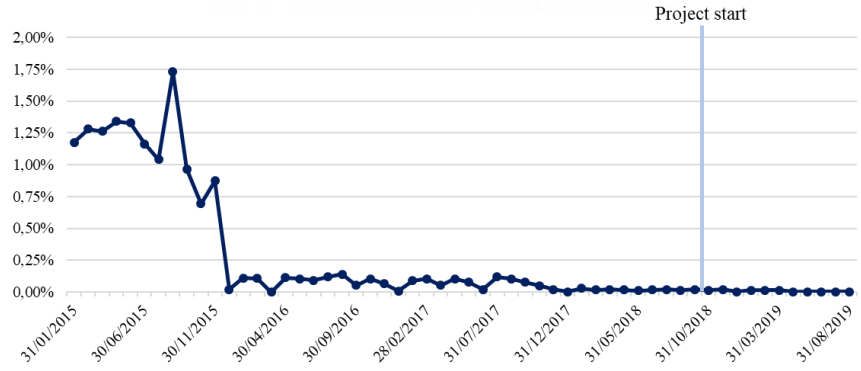
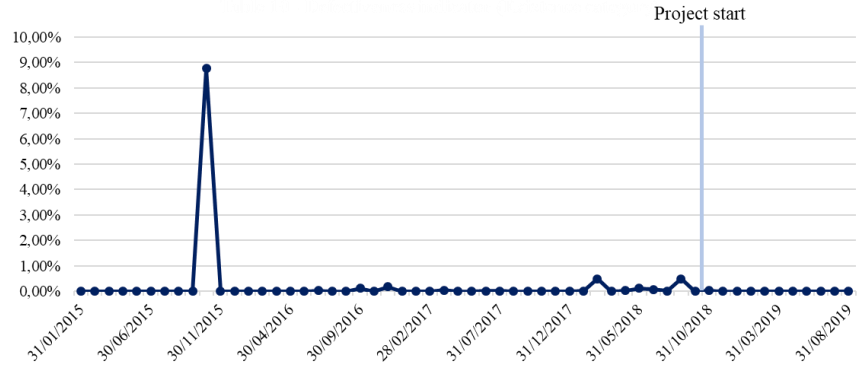


Table 10 - Defectiveness indicator (Existence category)



In order to enrich the information obtained by the visualisation of the KQIs' trend over time, a Mann-Whitney U test was carried out with the objective of verifying the existence of statistical difference, in terms of distributions, between the KQIs values for the period January 2015 - August 2018 (before project realisation), which constitute sample 1, and KQIs values for the period September 2018 – August 2019 (during project execution), which compose sample 2. With the exception of the KQIs calculated for Table 2, which refer to a given quarter, each value of the computed KQIs refers to a given month, since the underlying controls have monthly frequency. Thus, considering nine tables out of ten, for sample 1 sample size is 44, while for sample 2 it is 12. Referring only to Table 2, for sample 1 sample size is 14, instead for sample 2 it is 4.

As said before, in the first place the choice of the tables to analyse was guided by the decision to focus, within the whole perimeter of tables used for credit risk's metrics estimation only on a subset of tables, characterised by a substantial deviation of the KQIs from their initial value. Then, among all the tables exhibiting critical values for the KQIs, for the purpose of the analysis a random selection of tables was made.

A two-tailed test was performed, comparing the p-value against a significance level of 5%. A result is statistically significant when the p-value is less than the significance level α; this signifies that a change was detected and the null hypothesis can be rejected.

- If p-value > alpha: fail to reject the null hypothesis (i.e., not significant result);
- If p-value ≤ alpha: reject the null hypothesis (i.e., significant result).

It is important to remember that the p-value is probabilistic; this means that when interpreting the result of a statistical test only what is likely is known, not what is true or false. Rejecting the null hypothesis means that there is sufficient statistical evidence that the null hypothesis does not look likely, otherwise, it means that there is not sufficient statistical evidence to reject the null hypothesis.

Results are summarised below, together with the information related to the samples' median, used as central tendency indicator, and its related change.

Table	Indicator	Control / Category	P-value	Rejecting H_0	Median of sample 1	Median of sample 2	Percentage change in median
1	**Coverage**	Technical	0,000	Yes	87,500%	100,000%	14,286%
	Defectiveness	Coherency	0,000	Yes	0,005%	0,002%	-52,390%
2	**Coverage**	Technical	0,056	No	83,333%	100,000%	20,000%
3	**Defectiveness**	Date format	0,000	Yes	28,833%	0,000%	-100,000%
4	**Defectiveness**	Domain	0,001	Yes	1,715%	1,324%	-22,817%
5	**Defectiveness**	Consistency	0,000	Yes	5,367%	0,000%	-100,000%
6	**Coverage**	Technical	0,118	No	100,000%	100,000%	0,000%
	Defectiveness	Existence	0,000	Yes	0,057%	0,009%	-84,488%
7	**Defectiveness**	Univocity	0,092	No	0,523%	0,252%	-51,811%
8	**Defectiveness**	Univocity	0,000	Yes	0,135%	0,056%	-58,522%
9	**Defectiveness**	Completeness	0,003	Yes	3,192%	1,574%	-50,693%
	Defectiveness	Univocity	0,001	Yes	8,849%	5,116%	-42,189%
10	**Defectiveness**	Completeness	0,000	Yes	0,097%	0,007%	-92,485%
	Defectiveness	Existence	0,084	No	0,000%	0,000%	0,000%

The outcomes of the analysis, including both the visualisation of the KQIs trend over time and the execution of the Mann-Whitney U test, show a clear enhancement of data quality in the period under assessment. The Mann-Whitney U Test led to the rejection of the null hypothesis in 10 out of 14 cases, demonstrating that the distributions of the KQIs in the two macro-periods considered can really be regarded as statistically different.

It is, however, interesting to note that in some situations data quality began to improve even before starting the project, meaning that the bank had already enforced some remedial actions, although in a destructured way. With the objective of identifying the actual influence of the project on the data quality improvement, the Mann-Whitney U test was repeated, comparing this time the KQIs values for the period September 2018 – August 2019 (during project execution), which compose sample 2, with KQIs values for the smaller period January 2017 - August 2018 (before project realisation), which constitute sample 1. Therefore, considering nine tables out of ten, for sample 1 sample size is reduced to 20, while for sample 2 it is 12, just like before. Referring only to Table 2, for sample 1 sample size is 6, instead for sample 2 it is 4.

New results are showed below, providing also in this case the information of samples' median and its variation.

Table	Indicator	Control / Category	P-value	Rejecting H_0	Median of sample 1	Median of sample 2	Percentage change in median
1	**Coverage**	Technical	0,000	Yes	87,500%	100,000%	14,286%
	Defectiveness	Coherency	0,000	Yes	0,005%	0,002%	-52,565%
2	**Coverage**	Technical	0,571	No	100,000%	100,000%	0,000%
3	**Defectiveness**	Date format	0,000	Yes	0,625%	0,000%	-100,000%
4	**Defectiveness**	Domain	0,021	Yes	1,650%	1,324%	-19,776%
5	**Defectiveness**	Consistency	0,111	No	0,000%	0,000%	0,000%
6	**Coverage**	Technical	0,132	No	100,000%	100,000%	0,000%
	Defectiveness	Existence	0,021	Yes	0,013%	0,009%	-33,641%
7	**Defectiveness**	Univocity	0,115	No	0,529%	0,252%	-52,391%
8	**Defectiveness**	Univocity	0,000	Yes	0,113%	0,056%	-50,486%
9	**Defectiveness**	Completeness	0,015	Yes	2,604%	1,574%	-39,575%
	Defectiveness	Univocity	0,004	Yes	8,675%	5,116%	-41,031%
10	**Defectiveness**	Completeness	0,000	Yes	0,024%	0,007%	-70,098%
	Defectiveness	Existence	0,012	Yes	0,000%	0,000%	0,000%

6.4. Conclusions

Based on the obtained results, it is now possible to draw the conclusions of the analysis performed.

The first thing that can be noted by observing the data outlined in the previous paragraph is that most of the problems are related to defectiveness, rather than coverage indicator. This means that missing data contribute only in small part to low quality, which is most frequently due to not totally correct information entered into the IT systems. In this context, problems may be caused by human errors in manually entering data, technical issues in data transformation within IT systems and the reception from external and internal sources of already inaccurate information.

The other relevant point to remark is that, as before, the Mann-Whitney U Test led to the rejection of the null hypothesis in 10 out of 14 cases. Particularly, the only differences relate to Tables 5 and 10. For Table 5, the result of the first test allowed to reject the null hypothesis, while the outcome of the second test failed to reject H_0. For Table 10, it is the other way around; the first test failed to reject the null hypothesis, whereas the second test rejected H_0. All the other cases remained unchanged. These new results demonstrate even more that the distributions of the KQIs in the two macro-periods considered can really be regarded as statistically different and that the significant improvement in data quality can be attributed to the project execution. Moreover, also in cases in which the test failed to reject hypothesis 0, maybe because the starting situation was not so critical, a change in the value of the sample median occurred, specifically an increase for the coverage indicator and a decrease for the defectiveness one; the highest percentage change in median was 100%.

As a result, it is evident that data quality experienced a significant boost in the last years. In fact, all the tables under assessment show an improvement of KQIs, which in half the cases reach their target values, that is 100% for the coverage indicator and 0% for the defectiveness indicator. Even if some situations showed an improvement in data quality before September 2018 (start of the project), as the computed additional hypothesis test suggests, there is no doubt that TRIM Data Quality Credit Risk project is the main responsible for the enhancement in the quality of data used for the purpose of estimating PD, LGD and EAD models. This great achievement has been the result of a complex work, carried out for the most part in this last year, which required the cooperation of different working teams, mainly: business users responsible for the definition of risk strategies and initiatives and for the determination of the expected quality level, technology users accountable for the technical aspects related to the IT architecture supporting the overall data governance model; data office in charge of overseeing the definition, management and monitoring of the group-level data governance system, ensuring its consistency and effectiveness. For the purpose of measuring data quality and monitoring its level of adequacy over time, an extensive data governance framework has been put in place, characterised by production of documentation describing data lifecycle, implementation of controls aimed at detecting and subsequently correcting inaccurate data, definition of organisational processes related to the data quality framework and creation of data quality tools for the visualisation and reporting of processes' outcomes.

The complexity of the project is evident also looking at its considerable estimated cost; however, the opinion may change by looking at the same figure from another perspective. It should be, in fact,

outlined that if the bank did not start the project and consequently restore the compliance with the supervisor requirements, it would have seen its regulatory capital to be increased by the ECB; this of course would have taken to a cost much larger than the one incurred.

Finally, even if the TRIM Data Quality Credit Risk project was started for the need of responding to an obligation formalised by the ECB, the deliverable produced and the whole framework put in place will represent precious resources for the bank in the future, allowing it to extract increasingly value from its data.

LIST OF FIGURES

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